Topographic and Geologic Survey Commission of Pennsylvania

Report No. 5

TOPOGRAPHIC AND GEOLOGIC SURVEY
OF PENNSYLVANIA

REPORT No. 5

PRELIMINARY REPORT
ON THE
TALC AND SERPENTINE OF NORTHAMPTON COUNTY AND THE PORTLAND CEMENT MATERIALS OF THE LEHIGH DISTRICT

BY
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VIRTUE LIBERTY AND INDEPENDENCE

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INTRODUCTION.

GENERAL DISCUSSION.

The entire State of Pennsylvania, with the exception of a narrow strip along the Delaware River South of Trenton, New Jersey, lies within the Northeastern extension of that great physiographic unit of the Eastern part of the United States known as the Appalachian Province, which stretches from the Mississippi low lands on the West to the Coastal Plain on the East and from Alabama on the South, Northward to Canada. In the Northeastern extension of this province the State of Pennsylvania reaches nearly across its entire width so that within the Keystone State we find typically developed all the triple subdivisions which characterize it elsewhere.

The three grand subdivisions of this province, named in order from West to East are: 1. The Appalachian Plateau Division; 2. The Appalachian Valley Division, and, 3. The Appalachian Mountain and Piedmont Plateau Division.

In the State of Pennsylvania, we recognize portions of these three main subdivisions of the Appalachian Province, viz.: First, a segment Appalachian Plateau, which extends Westward from the front escarpment of the Allegheny Mountains and comprises the Western and Northern portions of the State or about sixty per cent. of its entire area. The rocks of the division are Silurian, Devonian and Carboniferous sediments and are for the most part but gently folded. The elevations range from 500 to 2,000 feet above sea level. Second, we recognize a portion of the Appalachian Valley division, which lies between the Allegheny escarpment on the Northwest, and the South Mountain and the Durham and Reading Hills on the Southeast. This division is composed of a series of parallel valleys extending Northeast and Southwest, separated by their corresponding parallel ridges which are know as the Appalachian Valley Ridges. The Valley Division in Pennsylvania has a width along the Southern border of the State of about 75 miles and narrows to about 25 miles on the Delaware River, where it passes from Pennsylvania into New Jersey and New York. The rocks of this division consist of lower paleozoic sediments for the most part, ranging from lower Cambrian to Silurian, and are as a rule highly folded and much disturbed by numerous faults. The elevations range from less than 200 feet along the Delaware River, to over 2,000 feet at the summits of some of the Valley ridges. In the

central part of the State the anticlines plunge to the Northeast and the synclines trough out to the Southwest, forming the characteristic "Cove topography" of that portion of the State. Third, we distinguish a portion of the Appalachian Mountain and Piedmont Plateau Division, which lies Southeast of the Valley division and embraces most of the Southeastern corner of the State. This division is clearly demarked from the Valley division in the Southern part of the State by the Northeasterly extension of the Appalachian Mountains in Pennsylvania, known as the South Mountains, which are composed of altered precambrian eruptives, and in the Eastern portion of the State along the Delaware River, by the Southwesterly promontory like extension of the Highlands of New Jersey, which are composed of ancient highly metamorphosed sediments of probable Algonkian age and crystalline gneisses with granitic and other intrusives of probable Archean age. The rocks of the Piedmont Plateau division consist (a) primarily of precambrian gneisses and schists with numerous granitic and pegmatitic intrusions. (b) The same early palaeozoic sediments which form the floors of the Southern Valleys of the Valley division also invade the Piedmont division in the low lying region between South Mountain and the Durham and Reading Hills, and form the surface rocks over a large part of Lancaster County. (c) In addition to these Precambrian and early palaeozoic rocks, the Piedmont Division is traversed from Northeast to Southwest by a continuous belt of red sandstones and shales, the Newark Series, which has a separate geologic history, a description of which will not be necessary in the present discussion.

LOCATION AND EXTENT OF THE AREA UNDER DISCUSSION.

The area which forms the basis of the present discussion, occupies the central portion of Lehigh and Northampton Counties, in Eastern Pennsylvania, and stretches across the Delaware River into Warren County, New Jersey. As will be seen from the accompanying small map of the State, it lies in the Southern portion of the Appalachian Valley Division, South of the Kittatinny or Blue Mountain Range which is the Southernmost of the Valley Ridges in the Eastern part of the State, and forms a prominent topographic feature North of the area to be described, while the Durham Hills form an equally sharp boundary on the South.

This Southernmost and most prominent of the valleys of the valley division in the Southern portion of the State is known as the Cumberland Valley. In the central portion of the State, East of the Susquehanna River, it continues under the name of the Lebanon Valley. Across the Delaware River in New Jersey it is known as the Kittatinny Valley.

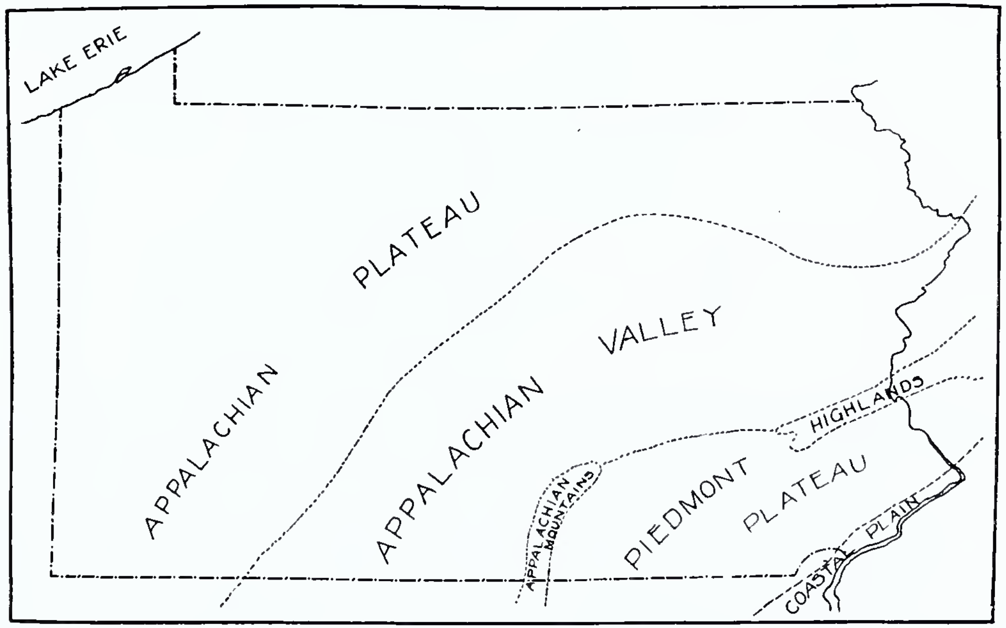

Figure 1. Map showing the physiographic divisions of Pennsylvania.

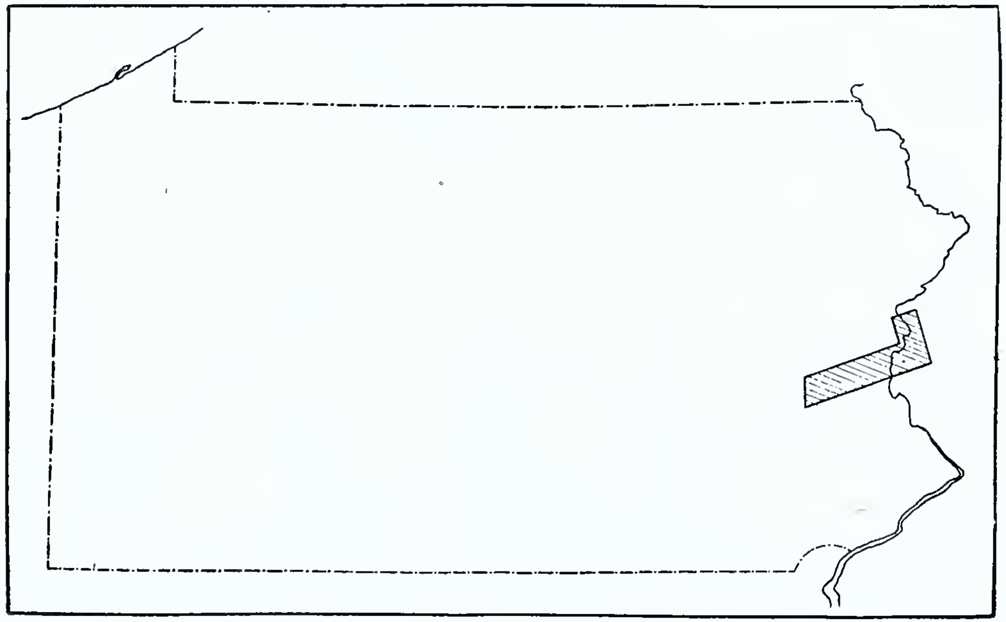

Figure 2. Map showing the area covered by this report.

It is the two-fold purpose of this paper (A) to discuss the geological mode of occurrence, preparation, and uses of the talc and serpentine as they are found in the Eastern part of the State and (B) to describe the geology of the region commonly known as the Lehigh Portland cement District, and to give a brief history of the development of the Portland cement industry in Pennsylvania, together with a description of methods of manufacture.

GEOLOGY OF THE TALC AND SERPENTINE DEPOSITS.

Inasmuch as the Talc and serpentine deposits of Eastern Pennsylvania (and Western New Jersey), are associated with the Precambrian rocks of the region, a somewhat general discussion of the different types of precambrian rocks will be attempted in connection with the discussion of the talc and serpentine beds proper.

The Precambrian rocks of the region with which we are dealing constitute the Southwestern extension of the Precambrian ridges which form the Highlands of New Jersey. Along the Eastern border of the State these precambrian ridges enter the State between Sandt's Eddy on the North and Monroe on the South, having a trend of about South 60° W, separated by intervening valleys of Cambro-Ordovician dolomites and dolomitic limestones. In Pennsylvania as previously stated these precambrian ridges go by the name of the Durham and Reading Hills. They extend in a Southwesterly direction as far as Reading, where they disappear beneath the floor of the Cumberland Valley.

CHARACTER OF THE PRECAMBRIAN ROCKS OF THE DURHAM HILLS.

No attempt is here made to separate the different kinds of precambrian rock cartographically or to describe them in detail. For present purposes the following general description will suffice.

Five kinds of rock compose the great mass of the precambrian Crystallines of the Durham Hills:

1. Fine grained pinkish to grayish gneiss of pronounced acid type, with indistinct foliation planes and of granitoid appearance. About three-fourths of the rock consists of nearly equal parts of orthoclase, microcline, and Sodaorthoclase, the remaining one-fourth being mostly quartz. The only dark constituents are biotite or hornblende which occur sparingly in small flakes or grains scattered through the rock. They are usually much decomposed and stain the rock with rusty brown spots.

An analysis of this acid granitoid type of gneiss, gave

$Si\ O_2$	75.07
$Al_2\ O_3$	12.07
$Fe_2\ O_3$ and $Fe\ O$	3.07
$Na_2\ O$	3.07
$K_2\ O$	5.11
$Ti\ O_2$	.21
	98.60

2. Coarse to fine grained dark colored gneiss of basic type, with distinct foliation planes, consisting largely of the dark minerals hornblende and augite in varying proportions. The subordinate feldspar is of the variety known as Labradorite. Usually quartz is absent but it may appear in considerable quantities.

The feldspar or the hornblende may alter to epidote giving the rock a yellowish green appearance. Analysis of this basic type of gneiss gave

$Si\ O_2$	63.30
$Al_2\ O_3$, $Fe_2\ O_3$	18.82
$Ca\ O$	4.58
$Mg\ O$	3.82
$C\ O_2$ & H_2O	9.68
	100.20

3. In the Northernmost of the precambrian ridges e. g. in Chestnut Hill, North of Easton, occur beds of coarsely crystalline limestone, sometimes quite pure, but locally rather highly magnesian and sometimes carrying considerable amounts of infiltrated silica. These beds of carbonates are in part composed of coarsely granular pinkish calcite with numerous scales of hair-brown mica (phlogopite), light-green hornblende, or light-green pyroxene, or perhaps a colorless variety of the latter mineral. Again, certain of these carbonate beds are composed of light-grayish or cream-colored, fine-grained, dolomitic limestones, with included silicates; or again many consist of a coarsely granular pearl-gray dolomite. These rocks are well shown at Lower Harmony, N. J., and in Marble Mountain one and one-half miles North of Phillipsburg, N. J., also at various points along the Southern slope of Chestnut Hill, North of Easton. The total thickness of these dolomitic and silicious limestones ranges from 30 to 75 feet.

The following is an analysis of a typical specimen of the coarsely granular siliceous limestones, where the silica percentage is high:

Silica (SiO_2),	48.40
Alumina (Al_2O_3), Iron (Fe_2O_3),	5.96
Lime (CaO),	22.46
Magnesia (MgO),	.80
Carbon dioxide (CO_2),	22.20
	99.82

The following is an analysis of the dolomitic variety of the same series:

Silica (SiO_2),	.28
Alumnia (Al_2O_3), Iron (Fe_2 O_3),	2.38
Manganese oxide (MnO),	.60
Lime (CaO),	31.80
Magnesia (MgO),	19.62
Carbon dioxide (CO_2),	45.20
	99.88

4. Above this limestone series, though separated somewhat from it by dark gneiss, occurs another unusual series of beds which consists of talcose rocks of light color, passing into grayish-green chloritic rocks more or less slaty in character, containing pebbly beds, jaspery beds of impure hematite, or beds of very pure hematite in rapid alternation. On the summit of Marble Mountain, N. J., these beds have a thickness of 50 to 75 feet, and years ago were prospected quite extensively for iron ore, but without paying results.

This hematite-bearing series is followed by gneiss of the basic type just described, some of which is more or less calcareous.

These two exceptional and totaly different series, 3 and 4, have been observed together at but a single locality, viz.: North of Easton, Pa., and Phillipsburg, N. J., in Chestnut Hill and Marble Mountain. They are of special interest for two reasons. In the first place they are of undoubted sedimentary origin, and secondly, it is in connection with these beds that the Talc and Serpentine deposits to be described later, occur.

5. Intersecting these different kinds of rock are to be found ingeous intrusions of various sorts, notably granite and pegmatite, with occasionally dikes or bosses of diabase or diabase-like rocks.

With this brief general description of the chief varieties of the precambrian rocks, we may now proceed with a more careful consideration of those beds among them which are of special interest economically.

THE TALC AND SERPENTINE BEDS.

The Talc and Serpentine of central Eastern Pennsylvania occur in a narrow band along the Southern slope of Chestnut Hill, North of Easton, and can be traced continuously for three and one-half miles. A short distance north of Chestnut Hill and slightly west of north from Easton, similar rocks occur, the relation of which to the other precambrian rocks, is somewhat obscure.

DESCRIPTION OF THE TALC-SERPENTINE ROCKS BY QUARRIES.

The accompanying map shows sixteen localities, all lying to the northward from the cities of Phillipsburg and Easton and within 2½ miles of them, at which rock of either a talcose or serpentine nature occurs. The better grades of talcose rocks are ground to a pulp (as will be more fully explained later) and sold for different purposes, while the serpentine is quarried in large blocks, sawn into slabs and polished or otherwise prepared for decorative purposes. Certain grades of this serpentine rock are also ground for mineral pulp. Ten of these sixteen localities either are or have been producers of rock in sufficient quantities to merit the name of quarries. Of these ten quarries, four are no longer producers; two are worked intermittently and four are steady producers. Two of the quarries are producing materials of two kinds, viz.: the ordinary rock for grinding purposes, and a rather superior quality of serpentine rock used for interior decoration.

All of these quarries have been opened up on beds of rock belonging to the same geologic horizon, and while the rocks in any particular quarry vary quite widely in character, all of the varities of rock there found can be duplicated in some one or more of the other quarries.

Warne's quarry.—Quarry designated "a" on the map is leased and operated by the Lizzie Clay and Pulp Co., of Phillipsburg , N. J., and is the only quarry at present being worked on the New Jersey side of the Delaware River. It was opened 24 years ago by Mr. E. J. Warne, and is known as Warne's quarry. It is one of the largest of the region and consists of an open cut 100 feet deep reaching to a considerable distance below the low-water level of the Delaware River. This necessitates some pumping to keep the quarry dry.

The character of the rocks in this quarry may be taken as typical for the entire region. It furnishes rock for commercial materials of two sorts, viz.:

(1) Rock used in the manufacture of mineral pulp (ground rock), and

(2) Rock quarried in blocks for decorative materials—slabs, columns, etc.

The rock at present largely used in the manufacture of pulp is rather hard, compact, massive to very finely granular in texture, and very light green, or mottled green and white in color. It consists of a very intimate mixture of two or three different mineral species, chief of which is serpentine, which gives the rock its greenish color. The colorless portion consists of a lime-magnesia, silicate, having approximately the chemical composition of the colorless amphibole, tremolite. This mineral has undergone a partial alteration, by hydration and a loss of its lime, to talc, which shows as floury patches wherever the rock is struck with a hammer. The lime thus set free by the more or less complete decomposition of the tremolite, remains, in part at least, in the rock as a third constituent, through a small one, constituting usually not more than 2 or 3 per cent of the entire rock mass. Occasionally this aggregate of minerals has been so thoroughly kneaded together as to result in a hemogeneous mixture of its constituents, so that it assumes a uniform apple-green color, is tough and compact or very finely granular, has a splintery fracture and approaches very closely that variety of serpentine known as bowenite in all physical properties except that of hardness, which is only 3.5 instead of 5 to 6.

A complete chemical analysis of this sort of rock showed:

Analysis of Rock, from Warne's Quarry.

Silica (SiO_2),	45.23
Aluminum (Al_2O_3), and Iron (Fe_2O_3),	2.68
Lime (CaO),	1.41
Magnesia (MgO),	38.34
Loss on ignition,	12.30
	99.96

Specific gravity equals 2.66; hardness, 3.5.

This corresponds very closely to typical serpentine. It is rock of this character which is used in the manufacture of the better grades of pulp.

The rock from this quarry which is used for decorative purposes is essentially a serpentine, but is usually darker green in color than the rock used for grinding, for only the lighter colored rocks grind to a pulp of the desired whiteness. It is a mottled mixture of light and dark serpentine, occasionally sprinkled with grayish, pinkish or

flesh colored dolomite crystals and sometimes veined with streaks or seams of pure white, these streaks consisting of a compact to fibrous looking calcite, in which are embedded fibers of asbestos. Much of this rock furnishes beautiful polished slabs and columns and finds a ready market.

The inferior varieties of serpentine here found are the result of the alteration of a compact or finely granular (but sometimes coarsely granular) aggregation of mica crystals of the phlogopite variety. This alteration of phlogopite mica to serpentine was confirmed by chemical test, where a piece of the micaceous serpentine consisting of pseudomorphous serpentine after phlogopite had the following composition:

Chemical Composition of Micaceous Serpentine.

Silica (SiO_2),	43.62
Alumina (Al_2O_3), Iron (Fe_2O_3),	4.39
Lime (CaO),	0.00
Magnesia (MgO)	40.78
Alkalies undetermined.	
Water (H_2O),	9.95
	98.71

This alteration of phogopite to serpentine is not common. In other instances the same rock passes over into talc as might be expected, talc being the natural alteration product of phlogopite.

A confirmatory chemical test of pseudomorphous phlogopite rock identical in character to the one above described as altering to serpentine, but in this case distinctly talcose in character, showed:

SiO_2	54.58
H_2O	4.82

There appears, therefore, to be abundant evidence of the alteration of phlogopite either to serpentine or to talc.

A small amount of molybdenite has been found in the serpentine here. It occurs as thin flakes or films on slickensides.

Among the rocks of this quarry are pearl or ashy-gray dolomites and dolomitic limestones, of pre-Cambrian age, and not to be confused in any sense with the Cambrian dolomites of the newer formations of the surrounding valleys. These appear to be the original rocks from which the serpentinaceous, tremolitic and talcose rocks were derived. By shearing they pass directly over into greenish or grayish talc or talcose schists. This alteration would be possible in the presence of water containing silica in solution. These friable talcose rocks to a certain extent are quarried for grinding purposes. The entire

product of this quarry, except the blocks quarried for sawing purposes, is ground into pulp at the mill of the Lizzie Clay and Pulp Company, located at Green's Bridge, one-half mile southeast of Phillipsburg.

At localities numbered "b" and "c" are old openings of some 25 years standing in peculiar talcose and squeezed serpentine rocks which are of too impure a nature to be utilized for pulp. At "b" the rock is stretched and squeezed serpentine of very light green color, in which numerous small veins, lenses and irregular nodules of quartz occur. At "c" the rocks are distinctly talcose in character; are grayish or greenish in color and pass over into dark-green schists of a chlorite nature. These beds do not belong to the same horizon as the Talc-Serpentine beds on the Southern slope of Chestnut Hill, but appear to be near the contact of the Cambrian dolomites on the pre-Cambrian gneiss.

Whedon Quarry.—One-fourth mile southwest along the Deleware River road and 175 feet above it, on the Southern slope of Chestnut Hill, and behind the prominence, know as Anthony's Nose, occurs the old Whedon quarry "d", no longer a producer, though rather vigorously worked 25 years ago for materials similar to those now being taken from "a".

Sherrer Quarry.—At "e" is the largest and oldest quarry of the region. It was owned until 1898 by Abram Sherrer (now deceased), who opened the quarry nearly 60 years ago. It is a large cut, which opens directly on the Deleware River road, and has been driven into the Southern slope of the hill a distance of 150 feet. Almost from the beginning the value of much of the purer serpentine rock for wainscoting, mantels, columns, etc., was recognized, and from time to time Mr. Sherrer sold large blocks of it in New York at $30 a ton in the rough. This quarry is now being operated by C. K. Williams and Company, paint manufacturers, whose mills are located at Easton.

Adjoining this quarry, somewhat higher up on the hillside to the South is a quarry formerly known as The "Verdolite" Quarry.

In 1898 William B. Reed. then of Easton, formed a company and opened this quarry a little above the Sherrer quarry in a rock similar to that found in the Sherrer quarry, but differing in the larger amount of pinkish and flesh-red dolomite crystals scattered through the light-green serpentine. This rock Mr. Reed called "verdolite" (contraction of verd-antique and dolomite), and the company formed was known as "The Verdolite Company." They purchased the Sherrer quarry, and began operations for producing blocks for sawing on a somewhat extensive scale, with the result that considerable excellent material was produced. The blocks were said to have been sold in New York at from $2.50 to $10.00 per cubic foot in the rough, or, reckoning at 12 cubic feet to the ton, at from $30.00 to $120.00

per ton. The rock suitable for grinding, which is removed in quarrying the blocks, is utilized by C. K. Williams & Co., who now own and operate both this and the Sherrer quarries.

The rocks of this quarry are quite identical in character to those found in the Warne quarry, being more or less intimate mixtures of serpentine and pink dolomite, or serpentine and tremolite, the latter mineral being more or less thoroughly altered to talc. The rocks especially on the south side of the quarry have suffered a tremendous amount of shearing and squeezing, and are here very fissile and talcose. A typical sample of the rock used for grinding showed a portion soluble in strong hydrochloric acid amounting to 63.7 per cent. of the bulk of the rock, 2.2 per cent. of which proved to be calcite. The remaining 61.5 per cent. analyzed as follows:

Silica (SiO_2),	42.98
Alumina (Al_2O_3), Iron (Fe_2O_3),	2.30
Magnesia (MgO),	40.79
Water (H_2O),	13.73

This analysis corresponds closely to typical serpentine. The insoluble portion, after being boiled in a strong solution of corbonate of soda, gave

Silica (SiO_2),	60.15
Alumina (Al_2O_3),	0.82
Iron (Fe_2O_3),	0.82
Lime (CaO),	8.52
Magnesia (MgO),	27.75
Alkalies undetermined.	

which can be considered as a partially decomposed tremolite, from which a portion of the lime has been leached, and which is in process of alteration to talc.

A short distance above this quarry are the ledges of verdolite which first attracted Mr. Reed's attention, and it was here that the Verdolite Company first began operations.

Fox quarry.—A short distance farther up the hillside takes one into the quarry known as the Fox quarry located at "f," which was opened some 20 years ago, and which has been a steady producer of pulp rock ever since. The quarry is located on what was formerly the property of the Verdolite Company, but is now owned and operated by C. K. Williams & Co., the most extensive pulp manufacturers of the region. The rock is lowered by an inclined tramway to the highway along the Delaware River and conveyed from there to mills owned by the same company located along the Bushkill Creek, just north of Easton. This quarry has been excavated in tremolite rock, which lies in heavy beds nearly 50 feet thick, and

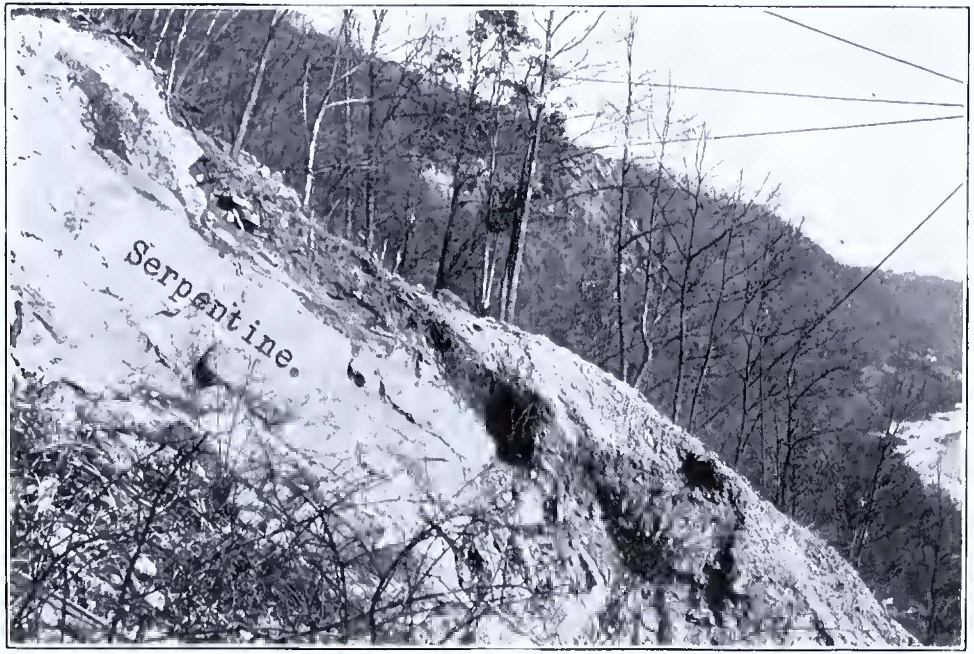

Plate II A. View of serpentine ledge in the old verdolite quarry.

Plate II B. View in the Fox quarry North of Easton, showing ledges of rock made up of serpentine, and talcose material formed from partly altered tremolite, which is ground into mineral pulp.

dips south under the granite which constitutes the southern wall. On the northward it lies on granite and gneiss. Evidently this rock has been faulted into its present position. The shearing to which it has been subjected has partially altered the tremolite to talc along the shearing planes. Scattered through this finely crystalline, sometimes massive white tremolite rock, are seams and irregular aggregations of what was originally phlogopite or pyroxene, now altered thoroughly to a handsome apple-green serpentine, which contrasts beautifully with the white tremolite. Microscopic thin sections of the rock show a felt-work of interlacing needles of tremolite through which is scattered a subordinate amount of colorless, or nearly colorless pyroxene, probably of the diopside variety. The tremolite shows all stages of alteration to talc, and the pyroxene changes to a cloudy, very light, yellowish-brown serpentine. A small amount of a very fine quality of talc is found along the shearing planes, as is also a small amount of asbestos. All the rocks at present used in the manufacture of pulp by C. K. Williams & Co., comes from this and the Verdolite quarry.

The following analyses are of specimens of rock from this quarry.

Analysis No. 1 is a very light yellowish-green rock consisting of a finely granular aggregate of micaceous material.

Analysis No. 2 is of a much darker rock, which is a typical specimen of the darker colored material used for grinding.

Analyses of Serpentine Rock from Fox Quarry.

	I.	II.
Silica (SiO_2),	46.80	42.94
Alumina (Al_2O_3), Iron (Fe_2O_3),	3.14	3.76
Lime (CaO),	.82	.67
Magnesia (MgO),	38.70	40.58
Water (H_2O),	10.64	12.00
	100.10	99.95
Sp. gr.,	2.64	2.57
Hardness,	3.5 to 4	3.5 to 4

Both of these analyses show the rocks to be essentially serpentine.

Lerch's quarry.—Quarry designated "g" is known as Lerch's quarry and was opened 30 years ago, but was abandoned and filled up, to be reopened 19 years ago by C. K. Williams & Co., who purchased it and the adjoining property. The rocks of the quarry are banded, made up of thin layers of streaks of much sheared white or grayish tremolite, alternating with light to dark yellowish-green bands of finely granular micaceous material, which is composed of phlogopite

scales in process of alteration to either talc or serpentine; or rather the first alteration appears to be to serpentine and from that they change to talc. These bands of mica scales themselves appear to be the result of squeezing and stretching or shearing and seem to form along planes of movement. Their subsequent alteration to talc is the result of shearing and stretching. Small grayish calcite or dolomite crystals are at times abundant, constituting 20 per cent. of the rock. Considerable free quartz in nodules and films, much crushed and milky white in color, is also occasionally to be found. This banding is due to the squeezing and shearing of the beds, which at present dip at from 30-40 degrees to the South. In the center of the quarry is a mass of much crushed coarsely granular pegmatite granite.

The quarry at "h" until recently has been operated by D. D. Wagner & Co., of Easton. The rock taken from it was ground to pulp in the two mills owned by the company located on opposite sides of the Bushkill Creek north of Easton. The rocks of the quarry are so similar in character to those of "g" that a description of them will not be necessary.

At "i" are two old open cuts, from which considerable talc of a rather superior quality was at one time taken. The talc itself was obtained from seams formed along shearing planes a few feet beneath beds of a dark basic-looking rock, sometimes coarsely granular, occasionally very fine grained in texture, consisting of green augite (now mostly altered to uralite), orthoclase and microperthite; also having much dark mica of the biotite variety, and some ore, probably magnetite. Talcose beds of considerable thickness occur beneath these biotite-augite-orthoclase rocks, which appear to take the form of beds dipping at an angle of 60° to the South and striking N. 55° E. The same beds shear also into chloritic rocks. Phlogopite in large masses, the crystals of which are two or three inches in diameter, is scattered about in the quarry and on the dump. Upon the latter trees eight inches in diameter are growing, showing thus the considerable antiquity of the workings.

Schweyer's quarry.—At "k" is a quarry opened 5 or 6 years ago by Mr. H. A. Schweyer, of King of Prussia, Montgomery county, Pa., near which he is operating extensive marble quarries. The property is owned by C. K. Williams, from whom it has been leased. This quarry was opened by Mr. Schweyer because of the exceptional promise here for dark and light-green serpentines, identical in character to those found at the other localities already described, but without the pink dolomite. It faces on the highway which runs Northwest through the cut made by the Bushkill Creek, through Chestnut ridge. The beds which are here exposed to a thickness of 75 feet, strike N. 55°-62° E. and dip 55°-65° S.

Plate III A. Schweyer's serpentine quarry on the Bushkill Creek West of Easton.

Plate III B. Mill where serpentine is sawn into slabs, owned by Schweyer Co.

Beginning at the north side of the quarry we have the following sequence of rocks:

(1) Ledge of coarse pegmatite granite 20 feet thick, apparently in the form of a much drawn-out lens or sheet lying parallel to the other beds and dipping with and under them to the South.

(2) Twenty feet of a dense, light to dark-green serpentine rock, or mixture of serpentine and tremolite.

(3) Ten feet of fine, even, granular pearl-gray to white tremolite mixed with more or less calcite or dolomite, or consisting largely of these two carbonates. It passes upwards into

(4) Similar tremolite beds with streaks of light to dark-green serpentine or mottled light-green and white mixtures of serpentine and tremolite or very light-green pyroxene (?).

(5) Cutting diagonally across these southerly dipping beds is a mass of coarse very light-colored pegmatite granite, which appears to extend downward and dip northward, and which we can suppose joins the lens or sheet of pegmatite first mentioned. Southward follow

(6) Thinner, less massive beds of lighter-colored serpentine-tremolite rock of essentially the same character as (2) and (4), which passes upward into

(7) Beds highly micaceous or distinctly talcose in character containing an abundance of phlogophite scales imbedded in rocks which were apparently highly calcareous or dolomitic, but which are badly decomposed. They have altered mostly to light-grayish or greenish masses of clayey or talcose materials, loose enough to be removed with pick and shovel. Resting upon these thinner beds to the south and dipping with them in that direction is

(8) A bed of dark-green, basic-looking rock, consisting of augite altered mostly to bluish-green hornblende; biotite; abundant plagioclase (albite); subordinate orthoclase; and much ore, probably magnetite. It is scarcely to be distinguished from the augite-orthoclase rock found at locality "i." The width of the quarry which has been opened up on these serpentine-tremolite beds is about 75 feet. The entire series, including the serpentine-tremolite rocks below and the more talcose and micaceous rocks above, is considerably more in thickness. The area is too badly covered, however, to ascertain accurately their thickness.

Across Bushkill Creek at "I" is a similar occurrence of rocks, formerly prospected, but never extensively developed.

Walter's Station.—There is but one remaining locality in this region from which either talc or serpentine has been obtained in commercial quantities. This is one mile east of Walter's Station at Kepler's Mill.

Here in a badly covered area, well out in the Cambrian dolomites and entirely isolated from the pre-Cambrian rocks of Chestnut Hill, are two open cuts "m" and "n" excavated in much squeezed and fissile talcose rocks, ranging from very light-green, almost pure white talc of a more or less fibrous or foliated character and of the best quality, through darker-green impure talcose rocks carrying much calcareous matter (as is shown by their rapid effervescence with hydrochloric acid). They contain also, pyrite cubes and dark mica scales; and are interfoliated with beds of fresh pearl-white tremolite. Immediately in contact with these talcose rocks, is a dark basic-looking rock, much jointed and contorted, apparently in the form of a sheet, dipping southward, but the disturbance has been too great to allow certain evidence. It is essentially the same macroscopically and microscopically as the basic beds found at "i" and "k."

Resume of the sequence of pre-Cambrian rocks in Chestnut and Marble Hills.

In brief the sequence of pre-Cambrian rocks as shown in Marble and Chestnut Hills, may be summed up as follows:

Reckoning from below upward, we find (1) Massive, rather granitoid gneisses, with indistinct banding or foliation, followed by (2) A series of beds of widely varying character, all of which are distinctly banded or bedded, and which are at least in part of undoubted sedimentary origin. Under (2) we distinguish the following sub-series, viz.:

(2a) Dark basic diorite gneisses, sometimes limy in character and altered to epidote;

(2b) Light colored feldspathic or sandy gneisses, sometimes limy in character;

(2c) Beds of limestone and dolomite:

(2d) Talcose and chloritic beds, carrying lenses and beds of more or less pure hematite, followed by other beds resembling (2a) and (2b) in character. Intruding all of the sub-series 2a-2d, and occurring usually in sheets or taking the form of much drawn-out lenses lying parallel to the banding or bedding, are numerous occurrences of coarse pegmatitic granite. Occasionally these pegmatites cut across the beds or surround angular fragments of the rocks which they intrude, suggesting veritable intrusions. In other instances they fade out into the surrounding rock in such a way as to suggest segregations.

In considering the above series as described, we are not to assume that the lower granitoid gneisses described under (1) are necessarily older than the overlying banded or bedded series (2a)-(2d), for the granitoid gneisses may prove to be true igneous intrusions injected into a pre-existing series, of which (2a)-(2d) were components, in which case they would be younger. Of this, however, there is no

positive evidence, and we çan at present affirm nothing with regard to the relative ages of the two series.

Alteration of the limestone-dolomite beds to talc and serpentine.—Wherever these pegmatites are found cutting the crystalline limestones and dolomite, or wherever they are found anywhere in their immediate neighborhood, the latter become utterly changed in character from their original condition. The contact effect of these granitic masses on the limestone-dolomite beds aided at least in building up in the one or more silicates of lime and magnesia, such as tremolite, pyroxene or phlogopite. Locally these silicates entirely replaced the original carbonates, but all intergradations can be found from nearly pure limestone or dolomite, containing but small amounts of the silicates, to rocks consisting wholly, it may be, of either pure white tremolite or white pyroxene, or an aggregation of phlogopite mica scales, or mixtures of these different mineral species.

These pre-Cambrian limestones and dolomites on the Southern slope of Chestnut Hill appear to be the vanishing point of that important series of crystalline limestones which enters New Jersey along its Northern boundary, South of Amity, N. Y., and which can be traced southward to Franklin Furnace and Sparta, N. J., and which appear again in isolated patches at Peqnest Meadows, Oxford Church, Montville and Lower Harmony.

At Lower Harmony the rocks are of the same general nature as those on the Southern slope of Chestnut Hill, but differ in detail. Tremolite, white pyroxene and phlogopite are wanting, but the limestone-dolomite beds were more or less altered to light-green hornblende, with the development of biotite and tourmaline and lenses of coarse feldspar and dark hornblende.

Then followed the subsequent alteration of these silicates of lime and magnesia to either serpentine or talc. In this alteration the tremendous forces which folded, squeezed, stretched and faulted the rocks into their present condition, together with the hydrating and leaching power of ever present water, were the principal factors.

GEOLOGY OF THE LEHIGH PORTLAND CEMENT DISTRICT.

In the following description of the geology of the cement district in Lehigh and Northampton counties, as in the description of pre-Cambrian areas, only a general statement will be attempted. So much work of a careful, painstaking nature remains to be done in working out the rather complex structure, and in determining the boundaries of the different formations of the region, that the present

paper can be regarded as little more than a repetition of what has already been written on the subject.*

In justification of the present description, however, it may be said that at present we are able, both on a lithological and on a palaeontological basis, to resolve the Cambrian and Ordovician system of this portion of the Great Valley district, into several horizons i. e., formations, not previously recognized, which can be correlated with those recognized and so admirably mapped and described by Mr. George W. Stose in Folio No. 170 of the U. S. Geological Survey, in which publication is to be found an exact and detailed description of the geology of the South Western extension of the same Great Valley district.

STATIGRAPHY OF THE LEHIGH DISTRICT.

The rocks of that portion of the Great Valley which we are considering begin at the bottom with lower Cambrian sediments, which lie unconformably upon the pre-Cambrian crystallines already described in the discussion of the geology of the Talc and Serpentine deposits. They are wholly of sedimentary origin and as regards geologic age belong to the two lowest periods of the Palaezoic era, viz.: the Cambrian and Ordovician.

CAMBRIAN SYSTEM.

The Cambrian system within this area consists of quartzites, calcareous and shaly sandstones, buff sandy shales, dolomites, dolomitic limestones, with a few beds of quite pure limestone. Named from below up the following formations may be recognized: Hardyston Quartzite, Leithsville formation, Allentown Limestone.

HARDYSTON QUARTZITE.

This term was applied by Kümmel and Weller to the basal Cambrian quartzites and Conglomerates of Northern New Jersey. In Lehigh and Northampton counties these rocks are found as a discontinous fringe around the borders of the pre-Cambrian gneisses. This quartzite series is not well developed in the Eastern part of the State along the Delaware River. It is to be found as a thin veneering wrapped around the east end of Morgan's Hill and along the northern margin of the same where it is so highly ferruginous as to constitute an iron ore. All of the mines to the South of Easton are

*Bulletin U. S. Geological Survey No. 243, Pages 279–294. "Cement Materials and Industry of the United States" by Edwin C. Eckel.
Economic Geology, Vol. III, page 37. "Geology of the Cement Belt in Lehigh and Northampton Counties, Pa." By F. B. Peck.
Science, Vol. 30, page 416. "Early Paleozoics of the Lehigh Valley." E. T. Wherry.

located on this ferruginous quartzite. Elsewhere, viz.: at Emaus and farther to the southwest in Lehigh county it has furnished considerable ore. It is best exposed within the area covered by the accompanying map along the Northern margin of South Mountain, South of Bethlehem. It is exposed at a number of places between Bethlehem and Allentown, and a number of quarries have been opened in it for building stone.

This basal member of the Cambrian begins at the bottom with a few feet of coarse conglomerate, which is followed by a typical arkose. This then grades into dense bluish or grayish quartzite having interstratified with it a few feet of impure, fine-grained quartzite. The uppermost member of the series is a very fine-grained, almost jaspery, frequently highly ferruginous quartzite. The series as above described cannot be seen at any one place, but at different points all of these different phases may be observed, appearing in the order named from below up. No fossils of distinctly lower Cambrian age have as yet been found within the area covered by the map but the same beds both to the northeast in New Jersey, and to the southwest in York county, Pa., have furnished abundant evidence of their lower Cambrian age. Certain beds of the quartzite furnish numerous casts of the tubes of Scholithus, a worm which burrowed in the sands on the beaches of the ancient Cambrian sea, and the old strand lines are in places clearly indicated by their presence.

The failure of the quartzite to appear along the margin of the pre-cambrian rocks is due to one of two causes: (1) It was never deposited, due to the fact that the continent was above water at that point during early Cambrian times; or (2) It has been faulted out of sight.

The Hardyston Quartzite varies in thickness from 0 to approximately 400 feet.

LEITHSVILLE FORMATION.

These conglomerates and quartzites pass upwards into a series of Calcereous sand rocks of medium fine character, which weather very readily by solution of the calcareous cement which holds the sand grains together, into an ochre-colored or rusty brown mass of sand. Locally the beds consist of light buff sandy shales. Higher up in series these sandy beds pass over into gray, sandy, Cherty dolomites, very tough and splintery, evidently with high silica content. The upper portion of the series is well exposed at Leithsville, 4 miles south of Bethlehem, while the lower portion of the series may be seen along the trolley line at the east end of Morgan's Hill. Generally speaking, the naturally destructable character of the lower portion of the Leithsville has resulted in rather marked depressions which fre-

quently border the pre-Cambrian areas. No fossils have as yet been discovered in this formation within the area under consideration but from the known age of the next succeeding formation it can confidently be referred to the lower and middle Cambrian.

Its exact thickness cannot be determined partly because of the covered character of the region and partly because of the difficulty in fixing the boundary between it and the next succeeding formation, so that on the accompanying map no attempt has been made to even approximately define its areal extent. It appears to be in the neighborhood of 1,000 feet thick.

ALLENTOWN LIMESTONE.

This is the most prominent member of the Cambro-Ordovician limestone series which underlies the Great Valley of this region. It consists of rather regular thin beds, from a few inches to a foot or more in thickness, of rapidly alternating light and dark dolomites or dolomitic limestones, with frequent bands of oölitic material, the upper surface of which is often covered with the coral-like organism, known as Cryptozoon (species, proliferum?), described by Hall and Walcott as occurring near the top of the upper Cambrian in New York, and identified by Ulrich and Stose in beds of the same age (Conococheague limestone), to the southwest in the region about Chambersburg. Shallow water conditions seem to have prevailed during the deposition of this entire series as is indicated (1) by the fact that well defined ripple marks are to be found at various horizons from the bottom up. The best example of ripple marks is to be seen in an old quarry three-quarters of a mile South of Raubsville, on the West side of the Delaware River. (Plate IV, B.)

(2) By wave breccias, i. e., flat or slender angular fragments of limestone, imbedded in a calcareous or magnesian mud as matrix. These flat-pebbled conglomerates or breccias seem to have been formed by the breaking up of thin beds of calcareous sediment while they were still soft by current or wave action in very shallow water, which angular fragments were then re-deposited with the soft mud that surrounded them as current or wave breccias.

(3) The numerous oölitic bands in this formation were doubtless formed by the oscillation of small particles at the bottom of shallow water by the rhythmical motion of the waves, about which particles the mineral matter in solution in the sea water could concrete, forming small concretions or spherules, which were subsequently cemented together to form oölite.

(4) Unmistakable cross-bedding can be noted occasionally, though this is not common. This indicates the rapid change in the direction of swift currents in shallow water.

Plate IV A. Cryptozoon, a low order of coral-like animal characteristic of the upper Cambrian. It appears in the photograph as light colored bands, curved upwards. It usually occurs immediately above a band of dark oolite.

Plate IV B. View in an old quarry near Raubsville, Pa., showing ripple marks in the Allentown limestone.

There were apparently times when temporary land conditions prevailed, though they were of such short duration as not to seriously interrupt the process of deposition.

On account of the rather complex folding of the beds, the thickness of the formation can be only approximately estimated. The maximum would perhaps be 1,500 feet.

As to the age of the beds, the presence of Cryptozoon in greater or less abundance through the entire formation indicates that the beds are upper Cambrian.

COPLAY LIMESTONE.

The Allentown dolomites and dolomitic limestones are succeeded by a series of dark blue heavy bedded dolomitic limestones passing upwards into thinner beds of mottled magnesian limestones with interstratified beds of nearly or quite pure limestone, the pure limestone beds increasing in frequency as the upper portion of the series is approached, until in the upper 300 or 400 feet they predominate. The dolomite beds can be readily told from the purer limestone beds by their lighter color and by their greater hardness and brittleness which latter property can be judged of by their jointed character. The joints in these hard, brittle dolomite beds are numerous, i. e., rather closely spaced, and are filled with white quartz, calcite or pearl spar, one or all. Numerous quarries have been opened in this upper portion of the Coplay limestone, the stone being used for flux, burned for lime and taken to the neighboring cement plants to be used in the manufacture of cement. The large quarry of the Lawrence Portland Cement Company, one-half mile north of Catasauqua has been opened in these beds. (Plate V, A.)

A few of the beds in the upper portion of the Coplay limestone are highly fossiliferous so that there is no lack of data for determining the age of the beds. Common among these fossil forms are large gasteropods of the genus maclurea, smaller spirally coiled gasteropods, pronounced by Mr. Ulrich to be Liospira and Helicotoma. Also orthocone cephalopods in considerable numbers, so that these beds may be considered to be of undoubted ordovician age and probably lower Ordivician or Beekmantown.

Above the Coplay limestone separating it from the next younger formation, the Nazareth limestone, there appears to be a rather pronounced erosional unconformity, so that the thickness of the Coplay formation is somewhat variable. It appears nowhere to be over 1,000 feet thick.

NAZARETH LIMESTONE.

Succeeding the Coplay limestone, which on the whole is prevailingly magnesian, comes a series of beds which in point of thickness and continuity is vastly inferior to the limestone formations previously described, being rarely if ever over 200 feet thick and diminishing

from that maximum to zero. From an economic standpoint, however, this comparatively insignificant series of pure limestone beds, is a most important factor in cement-making throughout the district, for the reason that much of the so-called "Cement Rock" which overlies the Nazareth limestone and which is the chief source of cement-making materials, is too low in its lime content for the manufacture of cement and must, therefore, have pure limestone added to it to bring the lime in the mixture of raw materials up to the proper percentage. As a result of these conditions large amounts of limestone are consumed, and the search for a pure article in large amounts has been very keen so that the majority of the limestone quarries, the product of which is used in the manufacture of cement, have been opened on these beds.

The beds of this series vary somewhat in lithological character and chemical composition. In color and texture they vary from light gray, fine even granular rocks, to rather dark almost black coarsely crystalline limestones in which the crystals of dark calcite are large enough to show distinct rhombohedral cleavage surfaces. These coarsely crystalline beds are apt to be highly fossiliferous. Towards the top of the series beds of distinctly slatey (argillaceous) limestone make their appearance, which beds mark the transition to the next succeeding formation, viz.: the Lehigh Limestone.

As regards chemical composition the beds vary considerably as may be seen from the twent-nine analyses given below. Each of these analyses is of a separate bed. The samples were taken from three adjacent quarries located about two miles west of Catasauqua, and illustrate very well the changes in chemical composition of the Nazareth limestone. The beds from which the samples were taken aggregate about 75 feet in thickness, and the samples were taken as numbered from below up. Only the percentages of carbonate of lime and magnesia are given, the remainder being chiefly silica and alumina with some iron.

ANALYSES OF THE NAZARETH LIMESTONE.

No.	$CaCO_3$	$MgCO_3$		No.	$CaCO_3$	$MgCO_3$	
1	89.50	1.92		16	92.90	2.10	
2	92.20	2.60		17	88.90	2.27	
3	94.00	2.27		18	91.30	1.92	
4	88.20	1.92		19	92.10	1.92	
5	87.80	1.51		20	84.80	1.52	
6	93.40	1.92		21	90.60	2.27	
7	91.00	3.20		22	65.80	19.49	4′ thick.
8	70.60	12.94	2′ thick.	23	94.00	1.76	
9	94.40	1.92		24	90.50	2.66	
10	72.20	11.18	4′ thick.	25	92.70	2.66	
11	66.50	18.73	1′ 6″ thick.	26	51.30	22.09	2′ thick.
12	90.30	2.43		27	84.70	2.60	
13	92.00	2.86		28	70.90	1.92	
14	96.60	1.51		29	88.90	2.10	
15	95.10	1.92					

Most of these beds are reasonably pure limestone and could be used in cement-making, though none of them are of first class quality, such as the famous Anvil limestone which maintains a content of 98 per cent of calcium carbonate. Some of the individual beds, as indicated by analyses 8, 10, 11, 22, and 26, are much too high in magnesium carbonate, more than 5 per cent. being prohibitive for cement manufacture. The average run of these quarries, however, would not exceed 3 or 4 per cent so that their entire output could be utilized without "cobbing" or sorting out of the high magnesian rock. These analyses give a very good idea of the chemical composition of the Nazareth limestone throughout the district.

The Nazareth limestone by the increase in frequency and thickness of the slatey or argillaceous beds in its upper portion, passes over so gradually into the next succeeding formation, viz.: the Lehigh limestone, that it is difficult, if not impossible, on lithological ground alone to separate the two formations. On the accompanying map, those beds of the lithological and Chemical character just described, lying in the horizon between the rather highly argillaceous Lehigh limestone above and the more prevailingly magnesian Coplay limestone below, have been represented as a single geologic formation, because they do form a reasonably well defined geologic unit, and the writer feels confident that in the final decision of the matter on paleontologic ground, these beds—or some of them—will be regarded as a distinct formation or stage, of Black River or possibly lower Trenton age. Fossils, though abundant in certain of the beds, are poorly preserved and are usually indistinguishable except on weathered surfaces. Certain of the beds appear to be wholly made up of organic remains of which slender crinoid stems are often the most abundant.

The Nazareth limestone to the east of the Delaware River in New Jersey has been shown by Kümmel and Weller to be separated from the underlying dolomitic limestones, which we now believe to be of Beekmantown age, by a distinct non-conformity. The basal member of this formation, considered by them to be the equivalent of the Trenton, has been clearly shown to consist of a limestone conglomerate, described as the "Basal Conglomerate," which marks the lower boundary of this formation. West of the Delaware River this basal conglomerate can not be clearly traced, partly because the rocks are badly covered along this horizon, and partly because of folding, overturned northward, accompanied apparently by thrust faulting by reason of which its lowest portion is entirely obscured. On account of the more soluble character of these purer limestones both in the upper Coplay and in the Nazareth formations, the horizon in which these rocks occur is apt to be represented by a distinct depression deeply covered with waste material.

LEHIGH LIMESTONE. "CEMENT ROCK."

As previously stated, the upper portion of the Nazareth limestone is characterized by thin beds of a shaly, highly argillaceous limestone. These shaly beds increase both in thickness and in frequency of occurrence toward the extreme upper portion of the formation, where by a somewhat sudden transition they pass over into a shaly, highly argillaceous series of limestones, in which the bedding is indistinct or unrecognizable. The beds, where distinquishable, are usually much thicker than in the underlying Nazareth series.

The rock is at times gray in color and shaly, breaking into small flat, irregular or pencil shaped fragments; at times dark drab, almost black and distinctly slaty in character, breaking into broad flat pieces, having a distinct irridescent sheen in the cleavage surface due to miscroscopic scales of graphitic material. It is to this rock that the name "Cement Rock" is generally applied throughout the district and for which the name Lehigh limestone is proposed, in as much as it reaches its maximum development where it crosses the Lehigh River, and for the further reason that it is universally used in the manufacture of cement throughout the so-called "Lehigh District."

As to thickness it is rarely more than 200 feet and in places disappears altogether. A glance at the map will show how variable it is. The complete disappearance of both the Nazareth and the Lehigh limestones in places, notably West of the Lehigh River, can be best explained by assuming that during Black River and Trenton times, deposition through this region was at first off shore in clear waters, during which time the Nazareth limestone was deposited. Or we may assume that the neighboring continent was so low that little or no erosion was possible and that, therefore, no deposition of terrigenous materials could take place along its shores, thus leaving the sea margins wholly free for the deposition of organic remains in the form of calcareous hard parts of different marine forms. This period of erosional stagnation may have been succeeded by a period of gentle uplift, after which only the finest and most thoroughly weathered materials would be swept from the land surface. These impalpably fine clayey materials would be mingled with the calcareous materials still accumulating, and be deposited simultaneously with them, forming the argillaceous limestones of the Lehigh variety. There appears to be no real unconformity between the highly calcareous Nazareth beds and the highly argillaceous Lehigh beds above them, though conditions of sedmentation seem to have changed rapidly from point to point within short distances, so that materials quite different in character were deposited simultaneously in adjacent areas of only

a few miles in extent, and subsequent investigation may show, that some beds here mapped as Nazareth limestone are really synchronous with the Lehigh limestone or *vice versa*.

The interrupted character of the beds of the Nazareth and Lehigh limestones may be explained by assuming that local, temporary land conditions existed where they are lacking. The isolated patches of these rocks are so near together that this hardly seems probable. The most natural way of explaining the decidedly patchy character of these formations is by postulating a period of elevation and subaerial erosion at the close of the Trenton period, during which these formations, the Nazareth and Lehigh limestones, were entirely eroded in spots, leaving patches of them here and there. Then followed the long period of submergence, during which the rocks of the next period, the Martinsburg shales, were deposited.

As regards age these beds are unquestionably the equivalent of the Trenton series in New York.

The chemical composition of the Lehigh limestone, though quite variable from bed to bed within distances of a few feet, is, particularly in its lower portion, admirably adapted for the manufacture of Portland Cement. A mixture of raw materials suitable for the manufacture of the best Portland Cement should have about the following chemical composition:

SiO_2 13.32 per cent.
Al_2O_3 (Some Fe) 6.67 per cent.
$CaCO_3$ 73. to 74.00 per cent.
$MgCO_3$ 3.84 per cent. not over 5.00.

The lime carbonate is here perhaps a little high. In actual practice the raw mixture before burning has between 73 and 74 per cent. of carbonate of lime. Quite generally throughout the district the beds of the lower portion of the Lehigh limestone while varying considerably and rapidly within short distances, in their general average chemical composition, have precisely the composition required in the manufacture of this article, so that from the same quarry all the materials desired for its manufacture can be obtained. In other instances, however, limestone or clay must be added to produce the proper mixture.

The variation in chemical composition of the beds which go to make up the Lehigh Limestone, is well illustrated in the thirty analyses given below, which were made from as many samples taken ten feet apart in sinking three drill holes, each to a depth of one hundred feet. These drill holes were made to test the character of the cement rock which lies immediately above the beds of Nazareth limestone, 29 analyses of which are given on page 28.

ANALYSES OF THE LEHIGH LIMESTONE (CEMENT ROCK).

Drill Hole No. 1.

Depth.	10 feet.	20 feet.	30 feet.	40 feet.	50 feet.	60 feet.	70 feet.	80 feet.	90 feet.	100 feet.
SiO_2,	18.58	19.76	22.30	21.84	13.30	6.08	12.40	20.90	12.82	15.54
Al, Fe_2O_3,	6.88	7.48	7.60	7.02	2.68	1.80	2.88	4.50	3.26	3.56
$CoCO_3$,	60.76	66.51	63.17	64.08	68.41	86.28	79.06	67.51	74.73	70.76
$MgCO_3$,	3.06	3.36	4.18	4.12	14.11	4.06	4.36	5.28	7.90	8.54

Drill Hole No. 2.

SiO_2,	20.16	17.12	15.48	15.44	15.60	15.14	23.06	19.42	11.58	18.46
Al, F_2O_3,	6.70	8.94	7.74	8.56	7.92	7.74	8.48	7.32	4.40	5.76
$CoCO_3$,	64.26	65.79	69.49	68.32	69.31	68.95	61.55	66.03	76.35	59.93
$MgCO_3$,	4.00	4.70	4.38	4.36	4.29	4.55	3.55	4.23	6.42	14.32

Drill Hole No. 3.

SiO_2,	19.00	20.40	21.90	19.78	18.42	15.96	23.90	18.32	15.14	13.10
Al, Fe_2O_3,	9.34	8.52	8.64	7.82	8.86	7.66	8.26	7.48	7.30	4.44
$CaCO_3$,	64.89	61.62	60.29	65.34	64.62	68.87	58.75	67.33	70.58	72.29
$MgCO_3$.	4.14	4.24	4.11	4.05	4.47	4.30	3.98	4.39	4.29	8.60

In these analyses it will be noted that the carbonate of lime content in the majority of cases ranges from 60 to 70 per cent., which is too low for cement-making purposes. Where rocks of this character are used as is the case in a number of quarries throughout the Lehigh District, considerable amounts of pure limestone, and correspondingly large amounts of less pure limestone, must be added to bring the mixture of raw materials up to the proper percentage of calcium carbonate, viz.; 73 to 74 per cent. (A mixture carrying 73.8 per cent. of calcium carbonate will make a cement having 62.5 per cent. of lime, which is about right). For every one per cent. which cement rock lacks of this amount of carbonate of lime, five per cent. by weight of pure limestone must be added to make the proper mixture. For example, if the rocks of a quarry average but 68 per cent. of carbonate of lime, it necessitates the addition of 30 per cent. of pure limestone, and a correspondingly larger amount of less pure limestone (74—68x5=30). The purer limestone of the Lebanon Valley, known as Anvil limestone, which is used by some manufacturers of cement in preference to the native limestone of the Nazareth variety, contains about 98 per cent. of carbonate of lime, while the native or Nazareth limestone let us assume will average but 88 per

cent. Obviously less of the Anvil than of the native or Nazareth lime stone would be required to bring a 68 per cent. cement rock up to the required percentage of carbonate of lime. The relative amounts of Anvil limestone (with 98 per cent. carbonate of lime), and of native i. e. Nazareth or Coplay limestone (with but 88 per cent. carbonate of lime) which would be required to make a proper mixture, where cement rock carrying but 68 per cent. carbonate of lime was available, can be shown by the following calculations:

$$\frac{74-68}{98-74} = \frac{6}{24} = 25 \text{ per cent. of Anvil limestone.}$$

$$\frac{74-68}{88-74} = \frac{6}{14} = 42.8 \text{ per cent. of Native limestone.}$$

This would mean that a cement plant manufacturing 3,000 barrels of cement daily from rock carrying only 68 per cent. of carbonate of lime, would consume but 240 tons of Anvil limestone whereas if Native rock were used 411 tons would be required. This calculation is based on the fact that it takes about 640 pounds of the raw mixture to make a barrel of cement. Many of the plants, particularly those along the Lehigh River and to the West of it, depend on the Native limestone for their needed supply, in which region the Nazareth limestone is well developed and favorably disposed for quarrying. In some cases the cement companies own and operate separate quarries for cement rock and limestone, in other cases they purchase their limestone from private owners of good limestone quarries. The companies whose properties are more favorably located on the boundary between the Nazareth and the Lehigh limestones may possibly obtain the materials necessary for cement making from the same quarry. In New Jersey where the Nazareth limestone is poorly developed or fails altogether, it becomes necessary to bring limestone from a considerable distance. There Anvil limestone is used in considerable quantities. Trial has been made of the precambrian crystalline white limestone of the Franklin Furnace variety but it has not proven altogether satisfactory on account of its high percentage of silica and the difficulty of grinding it. The cost of native limestone where it is hauled any considerable distance is about 60 cents per ton plus cost of unloadng, while the usual charge for the Anvil variety is about $1.10 per ton. The average of the native rock in carbonate of lime is about 88 per cent. while the Anvil limestone carries uniformly about 98 per cent. It will be easily seen that while the native rock is cheaper, more of it is required than of the Anvil rock and where long hauls of the native rock are necessary, the Anvil limestone may be as cheap, or cheaper.

Below are given additional analyses of the Lehigh limestone or cement rock from quarries located between the Lehigh and Delaware River and in New Jersey.

Analysis No. 1—Rock high in lime.

SiO_2	11.92
Al+Fe	4.56
$CaCO_3$	78.60
$MgCO_3$	3.07
	99.07

Analysis No. 2—Rock a little low in lime, requiring addition of but a little limestone before burning.

Silica	14.08
Al+Fe	7.50
$CaCO_3$	73.12
$MgCO_3$	4.56
	99.26

The above analyses were made from sample taken from the same quarry. No. 1 contains nearly the maximum of carbonate of lime for the Lehigh limestone while No. 2 contains very nearly the proper amount for cement making.

Analysis No. 3—Rock low in lime.

Silica	15.73
Al+Fe	7.92
$CaCO_3$	70.75
$MgCO_3$	3.77
	98.17

Analysis No. 4—Rock still lower in lime.

SiO_2	23.03
Fe+Al	8.74
$CaCO_3$	62.02
$MgCO_3$	4.68
	98.47

Analyses 3 and 4 were also made from different beds in the same quarry. Both are low in lime carbonate.

Analysis No. 5—Rock a little high in lime.

SiO_2	13.88
Al+Fe	6.58
$CaCO_3$	75.75
$MgCO_3$	2.70
	98.88

Analysis No. 6—Rock a little low in lime.

SiO_2	15.31
Al+Fe	7.49
$CaCO_3$	71.69
$MgCO_3$	3.91
	98.40

Analyses 5 and 6 were made from different beds in the same quarry and it will be seen that by mixing these extremes in proper proportions the desired amount of line carbonate could be obtained.

As a rule no cement rock having less than 70 per cent. of carbonate of lime is used in cement manufacture for the reason that too much pure limestone must be added to make a well-balanced mixture. The lack of an abundance of good limestone throughout the district is perhaps the greatest hindrance to the manufacture of cement. Now that competition has become so keen on account of the tremendous growth of the industry, resulting at times in over-production and in the inevitable fall in price of the finished product, only those plants find it possible to continue the manufacture of cement with a comfortable margin of profit which are so favorably located as to have all of their raw materials at hand. The additional expense of shipping limestone in considerable amounts might make all the difference between a successful and an unsuccessful business project. Recently this competition has been heightened by the manufacture of slag cement in considerable quantities, the chief producer being the United States Steel Corporation, whose plant is located at Pittsburg.

Toward the upper part of the Lehigh limestone formation, the content in carbonate of lime drops to between 50 and 60 per cent. and the rocks become distinctly slatey in character and resemble the over-lying Martinsburg Shales. These upper beds are altogether too low in lime to be used in the manufacture of Portland cement, though formerly they were utilized in the manufacture of the highly alluminous, quick setting, slow hardening cement of the Rosendale variety.

MARTINSBURG SHALE.

We have seen that shallow water conditions prevailed during the deposition of most of Cambrian and early Ordovician sediments and that temporary land conditions of such short duration as not seriously to interrupt the processes of sedimentation also probably prevailed. The most conspicuous of these unconformities occurs between the Coplay and Nazareth limestones. That another of these somewhat pronounced erosional periods occurred at the close of Trenton time, after the Lehigh limestone had been deposited, seems probable, chiefly because of the interrupted or discontinuous character of the Lehigh and Nazareth limestones. At numerous points West of the Lehigh River the Martinsburg shale is found immediately in contact with the Coplay limestone. In some cases this appears to be due to faulting. In other cases, as along the North and South border of Huckleberry Ridge, West of Allentown, faulting appears to be out of the question and this promotory or peninsula of slate seems to lie unconformably on the underlying Coplay limestone. It seems probable that another period of subaerial erosion intervened at this time and was of long enough duration to entirely remove both the Lehigh and the underlying Nazareth limestones in places. If this be true we may further postulate a temporary elevation of at least the marginal portions of the Trenton sea bottom above the surface of the water and a migration of the shore line of the South-easterly lying continental land mass toward the Northwest.

Then followed a period of depression with a migration of the shore line to the Southeast, and the deposition of the rocks of the succeeding formation, viz.; Martinsburg shales.

The rocks of this formation which are prevailingly shales and slate with sandy beds in the upper portion, are described in the Pennsylvania surveys under the name Utica and Hudson River shales, or formation No. III.

The formation was named from a locality where it is typically developed, viz.; Martinsburg, W. Va. It extends to the Northeast from that locality through Pennsylvania and Northern New Jersey, where the same formational name has been applied by the New Jersey State Geological Survey.

Most of the roofing slate produced in Pennsylvania comes from this formation. In 1908 Pennsylvania quarried nearly 62 per cent. of all the roofing slate produced in the United States, nearly all of which came from the region between Slatington and Bangor in Lehigh and Northampton Counties. Northampton county alone produced 74 per cent. of the Pennsylvania product, and nearly 46 per cent. of the entire out-put of the United States. The entire out-put of the State in 1908 was valued at $3,902,958. In addition to roofing

slate, this region is the only producer of slate suitable for mill stock, (i. e., black-board and school slate), in the United States. The economic importance of this formation is therefore apparent.

Unlike the boundaries between the Coplay and Nazareth limestones, or that between the Nazareth limestone and the cement rock, which are poorly defined on account of the intercalation of the upper beds of one series with the lower beds of the following series, the boundary between the cement rock and the Martinsburg shale, is sharply defined and the transition is sudden and abrupt. All of the rocks of the Lehigh limestone series, even the very poorest in lime, effervesce rapidly with dilute hydrochloric acid while the overlying Martinsburg shales do not.

A single bed of limestone has been found interstratified with the Martinsburg shale, which occurs about 100 feet above the cement rock horizon. It does not appear to be continuous but seems to consist of a series of lenticular masses reaching a maximum of 50 feet in thickness. It outcrops at a point one mile northwest of Cemmenton on Spring Creek and at two points two miles west of Bath on Catasauqua Creek. At the latter localities it is quarried and burned for lime for fertilizing purposes. It is impure and dolomitic in character.

The thickness of the Martinsburg shale is difficult to determine because of the extreme folding to which it has been subjected. It is probably not far from 3,000 feet. Its base consists of a typical greenish gray fissle shale in which the bedding is with difficulty discernible on account of jointing and slaty cleavage. The slaty cleavage dips quite uniformly at angles varying from 10 to 40 degrees to the South East. There appear to be two slate bearing horizons, one toward the bottom and another toward the top of the formation.

Broadly speaking, we may say that, both lithologically and stratigraphically, the Martinsburg Shale corresponds rather closely to the Utica and Hudson River shales of New York. Throughout the region under consideration however, no fossils have been discovered, but to the Southwest in the same formation fossils have been found which Mr. Ulrich of the U. S. Geological Survey, considers to be characteristic of the Lorraine of New York, which beds immediately follow the Utica Shale. It has been practically demonstrated, therefore, that the Martinsburg shale corresponds closely with the Utica and Hudson River shales of New York, and it may be considered as the uppermost member of the Ordovician.

SILURIAN SHAWANGUNK GRIT.

The only formation of Silurian Age which comes within the area of the map which accompanies this paper, is the Shawangunk Grit. These beds regarded by the earlier surveys to be the equivalent of

the Oneida conglomerate and the Medina sand stone of the New York series, compose the prominent ridge known as the Kittatinny or Blue Mountain Range, (the Southermost of the Valley ranges or ridges), which forms a continuous barrier along the Northwestern margin of the Lebanon and Kittatinny Valleys. The lower portion of this formation consist of coarse, gritty, rather heavy bedded sandstone; somewhat altered so as to resemble quartzite. These lower, somewhat pebbly quartzite-like sandstones pass upward into alternating beds of red and grayish sandstone which frequently show cross-bedding. Occasional thin partings of dark shale occur and in the extreme upper portion a single thin limestone horizon a few feet thick, occurs.

These sandstones, which are between 1,500 and 2,000 feet thick, are the Southwestern extension of the Shawangunk grits of New York and are therefore of earlier age than the Medina. They were formerly considered to be coarse marine sediments, deposited in an encroaching sea, but more recently they have been described as coalescing alluvial fan deposits, in part sub-aerial, and in part, perhaps, sub-marine or delta-like, which formed at the mouths of the ancient Silurian rivers where they emptied into the sea.

In the preceding description of the rocks of the region, little more than an outline has been attempted, but enough, perhaps has been said to give a reasonably clear idea of the stratigraphy of the region, together with the conditions attending the deposition of the different formations. For present purposes no mention need be made of the remaining portion of the Silurian system, or of the thousands of feet of Devonian and Carboniferous sediments which succeed the Shawangunk grits. Our attention must be confined quite wholly to the geology of the great limestone valley.

STRUCTURE OF THE REGION.

Folding. At the close of the Permian period came the great Appalachian Revolution which folded the 30,000 to 40,000 feet of Paleozoic sediments up into a more or less complex series of folds, the axes of which in the region under consideration (as generally throughout the southeastern part of the State) trend northeast and southwest. The force which accomplished this folding was exerted in a direction from the southeast toward the northwest, the titanic character of which can best be judged of by observing the effect which it produced upon the rocks of the region.

In the area of the Cambrian limestone, the rocks being heavier bedded, stronger and more resistant, yielded more by slight dislocation along joint plains and by occasional faulting; faulting is com-

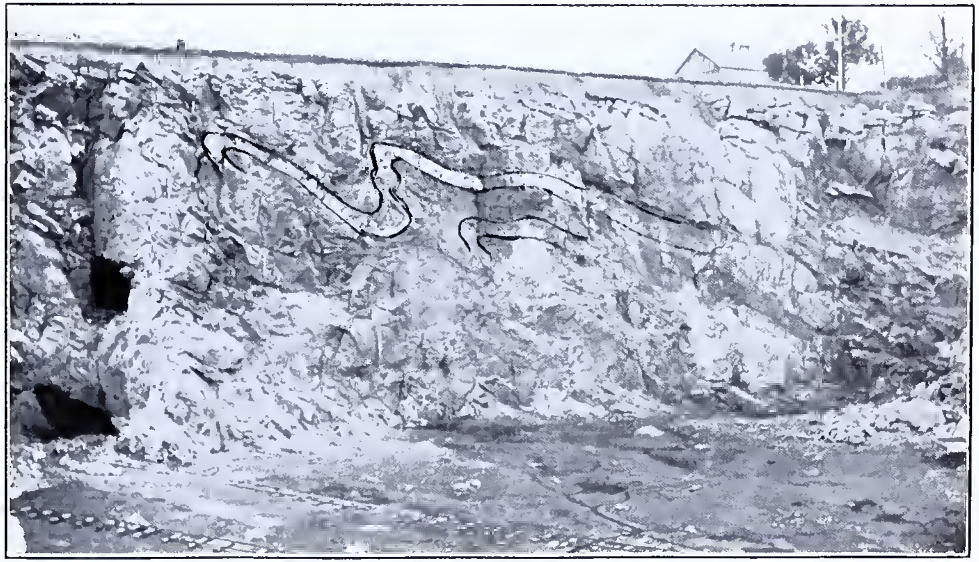

Plate V A. Showing folding in Coplay limestone. Quarry of the Lawrence Portland Cement Company at Catasauqua.

Plate V B. Fold in Coplay limestone in quarry South of Catasauqua.

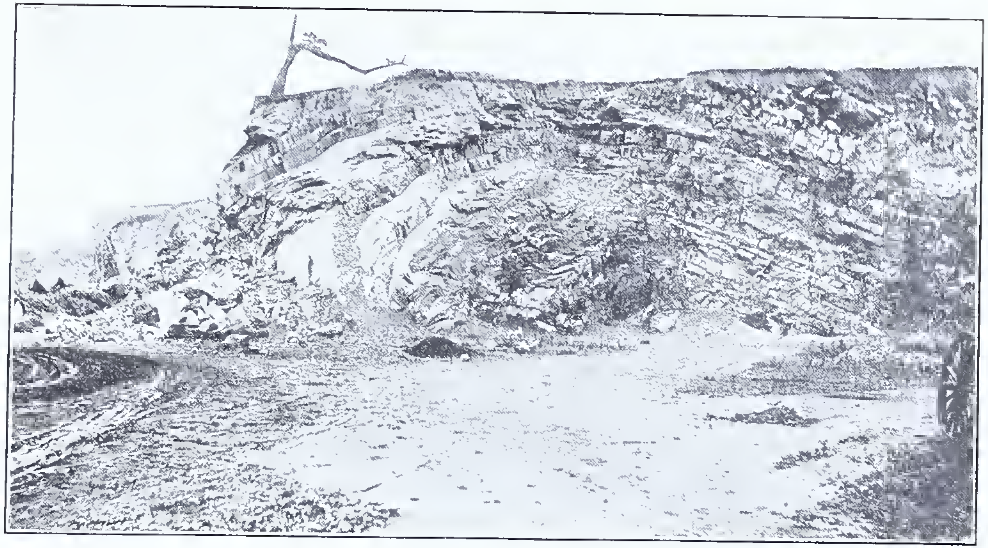

Plate VI A. Overturned fold in Coplay Limestone. Looking east in quarry near Guth's Station, Lehigh County.

Plate VI B. Showing overturned fold in Coplay limestone at Guth's Station, Lehigh County.

paratively rare in the Cement Belt proper. The cambrian limestone series was the competent structure by means of which the compressive stresses were transmitted a score or two of miles to the northwest. The softer Ordovician limestones, with their occasional interstratified beds of dolomite, yielded by folding, attended by some faulting and more or less flowage of the softer beds. It is in these beds that the extreme character of the folding is most clearly visible. The folds are usually closely appressed and frequently overturned to a greater or less degree to the northwest and are occasionally recumbent in this direction. Estimates made in one or two quarries in the limestone belt north of Catasauqua, show a crustal shortening of 6 to 1. That is to say, six miles of originally horizontal strata were mashed together into a single mile. The complex character of the folding under such conditions can easily be imagined. The accompanying figures show the character of the folding in the Coplay limestone.

In the cement and slate belts alike the rocks are of that weak yielding character which resulted not only in extreme folding but in more or less flowage, so much so that the original bedding is usually no longer distinguishable. Instead there is everywhere present that distinct slaty cleavage which usually dips to the south. At times, however, faint traces of the bedding planes can be distinguished, through the folds of which the cleavage passes at all angles.

Faulting. In the earlier accounts of the geology of the Great Valley region, faulting was considered to be wanting or of comparatively rare occurrence, but a closer study of this area, reveals numerous faults, some of which are of the first magnitude.

As a rule faulting is largely confined to the pre-cambrian and early paleozoic rocks which, on account of their harder and more brittle character, yielded under deformation by faulting more frequently than the softer rocks of the overlying formations.

Two systems of faults are easily discernible, one having a northeast, southwest direction parallel to the folds of the region. These are mostly of the type known as thrust faults, though normal faults having this trend are more or less common. The most conspicuous of these thrust faults forms the Northern boundary of the pre-Cambrian rocks of Chestnut Hill north of Easton. This fault has been traced both to the Southwest, where it forms the Northern boundary of the small out-lier of gneiss North of Bethlehem, locally known as the "Camel's Hump," and to the Northeast, along the Northern margin of Scotts Mountain in New Jersey, to Jenny Jump Mountain, a distance of 22 miles with a probable still farther North easterly extension. This thrust fault traverses the lower paleozoic rocks in a somewhat diagonal direction, with increased throw towards the Northeast, so that the pre-Cambrian gneiss cut across and over-ride

all of the Cambrian and Ordovician rocks of the valley. On the Northern slope of Jenny Jump Mountain, about 200 feet of black (Martinsburg) shale may be seen dipping to the Southeast, under the pre-Cambrian gneiss. If these shales prove to be of Martinsburg age, we have conclusive evidence of a progressive thrust fault, involving a displacement of thousands of feet and bringing the pre-Cambrian rocks into juxta position with the uppermost member of the Ordovician, viz.: the Martinsburg shale. It will be seen from the map that the gneiss of Jenny Jump Mountain has a small area of slate lying along its Northern border from which it is separated by the fault just described. This bit of shale, probably Martinsburg, has apparently been separated by erosion from the main portion of the Martinsburg shale lying one-half mile Northwest of it. It is here, too, that the Lehigh and Nazareth limestones disappear, leaving but a narrow interval of less than one-half mile between the main Northern area of Martinsburg shale and the pre-Cambrian gneiss of Jenny Jump Mountain.

These thrust faults are somewhat frequent along the Northern boundary of the pre-Cambrian gneisses, and are responsible to some extent for the discontinuous character of the Hardyston Quartzite, which in places has been faulted out of sight.

In addition to this Northeasterly-Southwesterly series of faults, there is a second series trending in a Northwesterly-Southeasterly direction and often intersecting the first series at nearly right angles, though sometimes rather obliquely. This second set of fractures is younger than the first and may be seen intersecting and off-setting the Chestnut Hill thrust fault at several places, notably at the Southeastern end of Chestnut Hill, West of Easton, and along the Northern Margin of Scott's Mountain South of Belvidere, New Jersey.

PHYSIOGRAPHY.

As previously stated, Lehigh and Northampton Counties, Pa., occupy a portion of the great valley extending across the Northern part of New Jersey and the Southeastern part of Pennsylvania, in a Northeasterly-Southwesterly direction and included between the Blue Mountain range on the North and the Highlands of New Jersey and the Durham and Reading Hills of Pennsylvania on the South. That portion of the Blue Mountain range to the North of the valley known as the Kittatinny Range is an even crested ridge having a maximum elevation of 1,600 feet above tide. The range of hills on the South of the valley is somewhat more uneven in character but presents a more or less continuous barrier, nowhere reaching an altitude of more than 1,000 or 1,200 feet above tide.

Plate VII A. View in quarry near Guth's Station, showing complex folding in Coplay limestone. The lighter colored beds are "hard limestone" or dolomite.

Plate VII B. Fold in Coplay limestone at Coplay.

Plate VIII A. Looking South on the Delaware River at Easton, showing the gneiss hills in the distance, the summits of which represent the Schooley Peneplain, and showing the intervening valley, the floor of which corresponds to the Harrisburg peneplain, in which the river has incised its present bed as shown at "a."

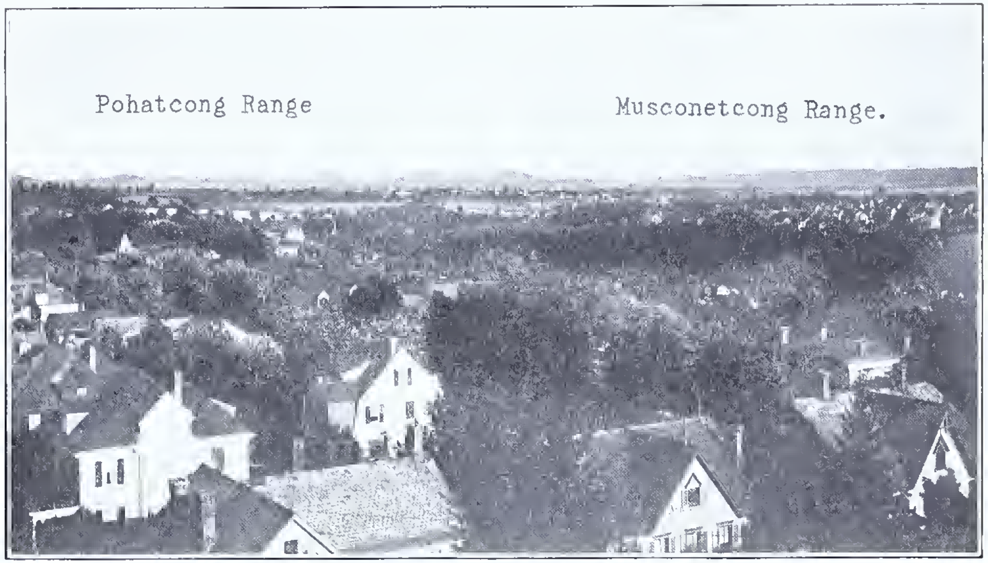

Plate VIII B. View Southeastward from Easton, Pa., toward the Pohatcong and Musconetcong ranges in New Jersey. The summits of these ranges form the sky-line in the distance, and constitute remnants of the old Schooley Peneplain. The floor of the valley of the fore and middle ground belongs to the Harrisburg Peneplain and is a portion of the Kittatinny Valley.

The summits of these two ranges are considered to be remnants of a once continuous and nearly level surface or peneplain which, at the close of the Cretaceous period, was of wide extent throughout the Appalachian region. This peneplain was the result of a base-levelling process which was in progress during the entire Mesozoic period and which resulted in bringing the entire land surface down to a monotonous or nearly level surface, out of which protruded a few prominences such as the Pocono Knob. This level surface, or plain of erosion was the result of the stream and atmospheric erosion which continued during the entire Mesozoic era, and which accomplished a complete cycle of erosion, producing what is known in the eastern portion of Pennsylvania and Northern New Jersey as the Schooley or Kittatinny Peneplain, remnants of which are to be found in the Pocono plateau and in the nearly horizontal even crested ridges to the South, notably Schooley Mountain and the Kittatinny range of Northern New Jersey and the ridges south of the great valley already mentioned. At this time the rivers of the region flowed lazily over this low-lying, nearly level plain, to the sea. Their work of degradation was accomplished.

At the close of the Cretaceous period there came a general elevation of the entire Appalachian region. Over the area under consideration it reached a maximum of 1,200 to 1,500 feet. This flat, elevated plane of erosion which had its maximum elevation over the Pocono plateau and the Kittatinny Range, sloped gradually to the South and Southeast, to the sea, where it disappeared beneath the Cretaceous sediments of central New Jersey between Trenton and Perth Amboy. As a result of this elevation, the rivers were given a new lease of life, and went at the task of again reducing the land area to the sea level with the result that they have accomplished only a part of it, viz.; an erosion of the softer or more soluble rocks of the valleys, leaving the harder rocks standing up as ridges, the summits of which, as already explained, constitute remnants of the Old Schooley or Kittatinny peneplain, which has been so called from the fact that these two mountains in Northern New Jersey, form conspicuous remnants of the old Cretaceous base level. This second partial base levelling process, which resulted in the reduction of only the softer rocks which underlie the broad valleys between the valley ranges, so conspicuously illustrated in the great Cumberland-Lebanon-Kittatinny Valley of Pennsylvania and New Jersey, created a second partial peneplain, co-extensive with the floor of these valleys, which has been called the Harrisburg peneplain, for the reason that the great valley in the region about that city is typical of it. Since the first general elevation of 1,500 feet, there are indications of a similar

general uplft over the same region of about 200 feet, and the rivers are now cutting their way down into this second or Harrisburg peneplain.

The valley throughout the cement district, as elsewhere, consists of two parts—a southern, covering the Cambro-Ordovician limestone and dolomite area and having a general altitude of about 400 feet above tide, and a Northern, coextensive with the slate hills region, or Martinsburg Shale area. The latter part, owing to the less soluble and more resistent character of the shale, has a general elevation of from 600 to 800 feet above tide, or an elevation 200 to 400 feet above that of the Southern limestone-dolomite area. The rocks used in the manufacture of cement are to be found along the boundary between these two subdivisions of the valley.

HISTORY OF THE ORIGIN OF THE CEMENT INDUSTRY AND DESCRIPTION OF THE EARLY METHODS OF MANUFACTURE.

DISCOVERY OF HYDRAULIC CEMENT.

The Romans were the first to use cement in any large way, and their discovery of it was purely accidental. They found that by mixing the reddish or grayish finely granular or sandy earth, which occurred in thick beds about and under the City of Rome, with lime, that the mixture possessed the valuable property of solidifying into a strongly coherent mass which time had only the effect of still further hardening and that this setting process would continue under water just as well as in the air, in fact that an abundance of water seemed to facilitate the process; that the cement thus made was far more durable than ordinary lime mortar; that mixed with broken stone or crushed tiling it formed a concrete which would outlast the most massive forms of stone masonry and continue to harden for centuries.

This reddish granular earth, called "Pulvis Puteolanus," for the reason that it was found abundantly about Puteoli (now Pozzuoli) was the essence of all of the Roman cements and later came to be known as Pozzuolana or Puzzolana. Accurately speaking, this Puzzolana is volcanic dust and fine lapillae which had been blown from neighboring volcanoes and which had accumulated in thick beds in their neighborhood. This volcanic material when mixed with lime had the essential chemical ingredients of the modern hydraulic ce-

ments. It was the mere accident of the propinquity of these volcanic ash beds, materials calcined at high temperatures in the vast subterranean kilns of volcanoes, which made the Roman cements so much stronger than all others and which gave them their reputation. From the time of the Roman Republic down to the discovery of the true nature of hydraulic mortars as exhibited in Portland cement, Puzzolana occupied a unique place.

The first modern hydraulic cements were manufactured in England. In 1759 a civil engineer by the name of John Smeaton, who had been engaged to build the famous Eddystone light-house (which had been twice destroyed, once by fire and once by storm), and who for that purpose required hydraulic cement which would withstand the action of sea water, discovered that by burning certain impure limestones containing from 15 to 25 per cent. of impurities in the form of silica and alumina, a suitable hydraulic cement could be produced. From that time on search was made all over England for hydraulic limestones from which to make this valuable structural material. In 1796 a man by the name of Parker discovered that by burning certain brownish clay-lime concretions called "bald-pates" or "captaria," which were found in the shales of the Island of Sheppey, an excellent hydraulic cement could be produced, and inasmuch as it resembled the ancient Roman cements it was called "Roman cement."

The increasing demand for hydraulic cements, however, combined with the difficulty and expense connected with collecting the necessary amount of captaria, led others to look about for more abundant and cheaper materials. In 1824 Joseph Aspdin, a Leeds bricklayer, took out a patent for an artificial cement which was made by lightly burning a mixture of lime and clay. This he called "Portland Cement" because of its resemblance when hardened to the famous building stone of the Isle of Portland. Two years later, viz.: in 1826, Major General C. W. Pasley, who had been appointed lecturer on architecture at the military school at Catham, began a series of experiments, the object of which was to produce an artificial cement which should be equal or superior to the so-called Roman cement. In this he appears to have been ignorant of Aspdin's cement. In 1830 he succeeded in making an article which experimentally proved to give perfectly satisfactory results. The materials used were Medway clay and chalk. The essential differences between these earlier forms of hydraulic cement and the modern were in the degree of calcination and in the thoroughness of the mixture of the ingredients. In earlier processes the calcination was not carried, as at present, to the point of incipient fusion, which is now recognized to be one of the essentials in the manufacture of the best grades of Portland cement. In fact that part of the burned material which showed signs of fusion

was rejected and in so doing they unwittingly discarded the most valuable product of the kiln; nor were the materials as finely ground or as thoroughly blended before burning.

From these beginnings sprang the Portland cement industry, which was at first confined to England, but which later spread to Belgium, France and Germany, and which by 1860 had become well established on the continent.

ORIGIN AND GROWTH OF THE CEMENT INDUSTRY IN THE UNITED STATES.

In the meantime the demand in the United States for hydraulic cements arose more particularly from the need of them in the construction of canals, notably the Delaware and Hudson, the Lehigh and the Chesapeake and Ohio. It was quite natural therefore that materials should be sought along the courses of these water-ways, which could be manufactured into the desired product. The search was not fruitless. Excellent hydraulic limestones were discovered at Rosendale and Rondout on the Hudson, at Siegfried and Coplay on the Lehigh, and at Hancock and Cumberland in Maryland. These impure argillaceous limestones were burned in kilns resembling ordinary lime kilns at a temperature sufficient to drive off the carbonic acid; the burned product was ground to a flour and sold in convenient packages as hydraulic cement. At Rondout and Rosendale, N. Y., large quantities of this natural rock cement were manufactured and the article was called "Rosendale Cement," which term has come to be more or less universally applied to all similar natural cements made by calcining natural hydraulic limestones at low temperature and grinding the product, no attempt being made at an artificial mixture. During the interval 1840-1875, the manufacture of these natural rock cements made considerable progress in the United States.

It was not until after the civil war, however, that true Portland cement became known in this country. From 1865 to 1876 it was imported in small but ever-increasing quantities from Europe until its value in construction had become well known. About this time a young farmer, David O. Saylor by name, who lived in Lehigh County, Pennsylvania, and who had been engaged in a small way in the manufacture of natural cement by burning certain argillaceous limestone which abounded in the region, conceived the idea of manufacturing a true Portland cement. He enlisted the interest and skill of another young Pennsylvanian, John W. Eckert by name, who had but recently graduated from the chemical and mechanical engineering courses at Lehigh University, and together in 1878 they succeeded in mastering the problem in spite of all the mystery and vigilance which surrounded

Plate IX. The first kilns erected at Coplay by David O. Saylor for the manufacture of Portland Cement; also three dome kilns subsequently erected by him.

the process, and in the following year (1879) constructed the first Portland cement works in the United States which produced the article on a commercial scale. From this small beginning sprang one of the largest and best established Portland cement concerns in the country, so well known as the Coplay Cement Manufacturing Company, whose works are located at Coplay, Lehigh Co., where from two to three thousand barrels of cement are now manufactured daily.

Shortly after the success of the first project had become assured, other cement companies were formed and began operations along the Lehigh River and in the adjacent townships in Lehigh and Northampton Counties, for which reason this, the original Portland cement producing region of the United States, became known as the "Lehigh Region." But during the last two decades the producing area has been much extended eastward across Northampton County to the Delaware River, and over the Pennsylvania border into Warren County, N. J.; also in a southwesterly direction to Reading, Pa. Within this district there are to-day a score of cement plants with capacities ranging from 800 to 35,000 barrels per day and representing a yearly output of over 20,000,000 barrels, which is roughly speaking one-third of the total annual production of the United States at the present time.

COMPOSITION AND NATURE OF HYDRAULIC CEMENTS.

Portland Cement. Portland cement is made by grinding together and to a very fine powder, a mixture of clayey and limy substances (the latter always some form of $CaCO_3$). This ground mixture is then burned or calcined to the point of incipient fusion, at which stage of the process it is known as "clinker." This clinker is subsequently ground and the ground product constitutes Portland cement. The mixture, however, must consist of certain definite proportions of the clayey and limy ingredients. The cementitious value or strength of the cement depends upon the chemical union of all of the lime of the limy ingredients with all of the silica (SiO_2) and all of the alumina (Al_2O_3) of the clayey ingredient, and there should be just enough lime to do this and no more in order to obtain the best results. This is known as the high-lime limit. Any excess of lime above this limit remains as uncombined lime which is perhaps the most common of the dangerous elements in poorly manufactured cement. Also the cement is liable to be of inferior quality: (1) if the materials, though present in proper proportions, are not thoroughly ground and intimately mixed; (2) if insufficiently burned; in this case the chemical union of the lime with the silica and with the alumina of the clay is not complete, so that a portion of the lime remains behind as free

lime. In the latter case when the cement is mixed with water the lime slakes, swells and causes the cement to crack or "blow." Cement of this sort is said to be unsound. This unsoundness may be hours, months or years in developing.

According to Messrs. S. B. and W. B. Newberry* the cementing principle of Portland cement was first thought to be due to the formation under the intense heat of burning, of two chemical compounds, which later, on coming in contact with water, hydrated and crystallized. These two compounds were determined to be (1) Tri-calcic silicate, $_3CaO, SiO_2$ and (2) Di-calcic aluminate, $_2CaO, Al_2O_3$. To the first of these compounds was attributed the slow hardening process of cement which extends over a period of months or even years and to which the final strength of the cement is largely due. To the latter was attributed the quicker setting property of the cement which begins to manifest itself possibly a few seconds or at most a few hours after mixing with water.

These conclusions, which are a modified form of LeChatelier's, have more recently been questioned by the researches of Day and Sheppherd,† who conclude that there is no such compound as tri-calcic silicate, but that the important substance which is responsible for the setting properties of cement is merely a solid solution of lime in calcium orthosilicates.

As previously stated, the raw materials from which Portland cement is usually manufactured, are carbonate of lime in the form of limestone, chalk or marl, and argillaceous matter in the form of clay, slate or shale. Occasionally, as in the region under consideration, nature has provided a mixture of clay and carbonate of lime in the form of an argillaceous limestone, or natural cement rock, which contains so nearly the theoretical proportions of lime, silica and alumina as to require but a small addition of limestone or clay or slate to make an ideal mixture. It may contain exactly the proper amounts of these ingredients, in which case no admixture of any kind is necessary. In the region about Bath and Nazareth in Northampton County, much of the cement rock is of this character. Along the Lehigh the character of the rock is such as to require the addition of some limestone, which is usually taken from the beds immediately underlying the cement rock. On the Delaware River at Martin's Creek the rock is apt to be too high in lime, which necessitates the addition of slate refuse or clay, while in Warren County, N. J.; the addition of limestone is necessary, most of which is obtained from the Lebanon Valley. In the majority of cases the addition of limestone is necessary.

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*Paper read before New York Section of Society of Chemical Industry, October 22, 1897.
†Journal American Chemical Society, September, 1906.

Plate X A. View of the quarry of the Lehigh Portland Cement Company at Coplay, showing old Atlas Mill, and old dome kilns of the Coplay Cement Company, where Portland cement was first manufactured. Also a steam shovel used in handling the cement rock.

Plate X B. Old dome kilns of the American Cement Company at Egypt. Looking southwest.

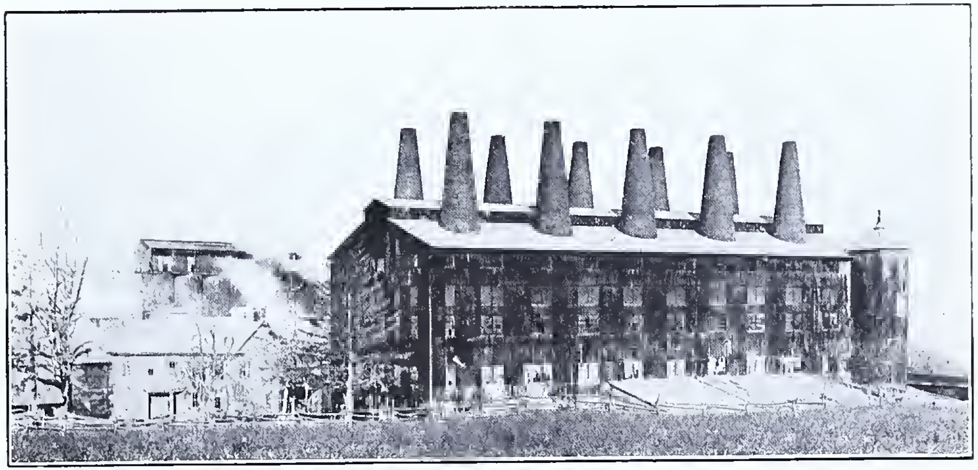

Plate XI A. Old Dietsch Kilns of the Coplay Cement Company, at Coplay.

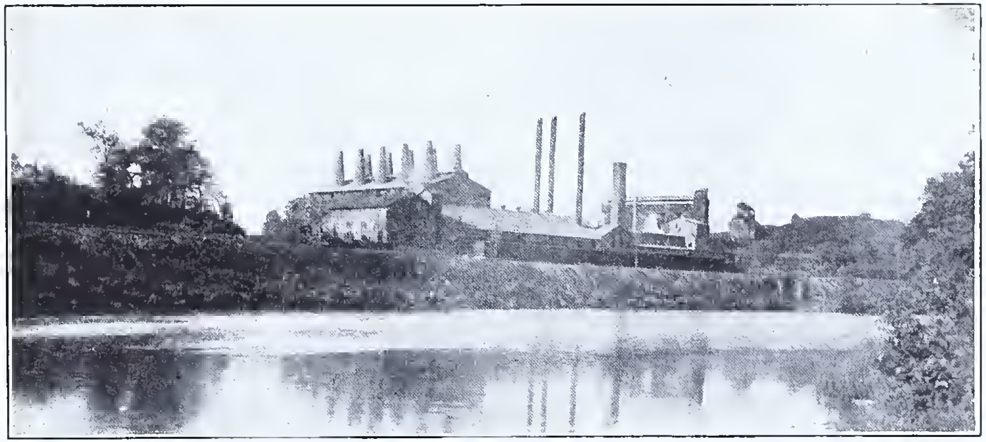

Plate XI B. The old Dietsch Kilns of the Coplay Cement Company at Coplay, from opposite (East) side of Lehigh River.

THE EARLIER AND MORE RECENT PROCESSES OF MANUFACTURE AS PRACTICED IN THE LEHIGH DISTRICT.

The earlier processes of manufacture in the Lehigh region were similar to those practised in England and may briefly be described as follows:

To the finely ground mixture of cement rock and limestone (containing of course the proper proportions of carbonate of lime, alumina and silica) was added enough water to make a rather fluid mass which was known as "slurry." This slurry was spread out on floors and when somewhat hardened by drying, was cut into bricks, which were thoroughly dried in various ways, usually by piling them up loosely along a series of steam pipes. These dried bricks were then burned in kilns, but at a higher temperature than in burning ordinary lime; as a result the bricks were semi-fused to a "clinker." The clinker was crushed, ground to a fine powder between mill-stones, and then constituted cement.

It would be well to explain here that most Portland cements set too rapidly. In order to retard the set two or three per cent. of sulphate of lime, either in the form of gypsum or plaster of Paris, is added, usually during the grinding of the clinker, in order to insure its thorough mixture with the cement.

Originally the kilns were of the kind known as "dome kilns" which were upright structures resembling somewhat ordinary lime kilns but having the lines of a blast furnace, which ensured a high temperature (white heat) during burning. Into these kilns the bricks were loaded with alternating layers of coke or coal. After burning the entire charge was drawn, so that the burning process was intermittent.

Another form of kiln came into use later in which the process was continuous. The amount of fuel (which was usually small coal) necessary for a proper calcination of the bricks was small as compared with the amount used in the intermittent kilns. These continuous kilns were known as the Dietsch Kilns, and the process of calcination was accomplished by stages. The working part of the kiln was divided into three chambers, upper, middle and lower. The dried slurry was loaded into the upper or heating chamber from which a portion of it was raked forward from time to time (usually every half hour or so) into the burning chamber, where at the same time fuel was added through separate eyes, and in which the process of calcining took place. From this burning chamber the clinker was allowed to settle into the lower or cooling chamber which was immediately below and from which it was periodically drawn. The principal reason for the economy of this kiln was the fact that air in passing upward through the heated clinker of the cooling chamber was raised to a high temperature before passing into the burning

chamber and on passing out through the heating compartment served to give the dried slurry a high initial temperature. While economical in the matter of fuel, it was expensive in other respects, more particularly in that it needed constant and skilled attention. Neither of these kilns are at present in use in the Lehigh region, although they might have been seen in operation fifteen years ago.

The Coplay Cement Manufacturing Company at Coplay is the pioneer Portland cement concern of the country. After the death of its founder, David O. Saylor, his associate, John W. Eckert, united with Robert W. Lesley in forming the American Cement Co.; and the original plants of these two companies furnish very interesting illustrations of all of the different processes which have been employed in the region, from the very beginning. None of them, however, are at the present time in operation, the rotary kiln having entirely replaced all other methods of calcining the ground raw material.

The method of manufacture as at present practiced throughout the region, including the manner of quarrying the rock, can be briefly described as follows:

Many of the quarries are located on hillsides and have long low working faces from which the rock is shot down in benches. Occasionally the quarries take the form of a pit which extends vertically down to the depth of one hundred or more feet, the depth depending upon the age of the quarry.

Inasmuch as the individual beds vary considerably in their lime content, it becomes a problem to select from different parts of the quarry such a mixture of rock as, when ground, shall approach most closely the ideal mixture. Usually a varying amount of pure limestone, slate or clay from a neighboring or distant quarry must be added to produce a well-balanced mixture, while more rarely all of the necessary materials can be selected from the same quarry. Sometimes the rock is loaded into small cars which run from the quarry face on a series of temporary tracks which radiate to different parts of the quarry from a convenient point, thereby facilitating a mixture of the different grades of rock in the quarry. The loading is accomplished by hand or rarely by steam shovel and the cars are run by gravity or drawn by mules or cable or pushed by hand to the mill. At other times an over-head tram is employed.

At the mill the rock is crushed usually in gyratory crushers, then dried in rotary driers to which later the necessary amount of limestone or slate, also previously crushed and dried, is added. After further reduction the mixture passes to ball mills and from them for its final reduction to tube mills, after leaving which it is conveyed to storage bins preparatory to feeding to rotary kilns. In some instances instead of the ball and the tube mills the reduction is accomplished by the Griffen or Huntingdon mill. The mixture when

Plate XII A. View of the quarry of the Nazareth Portland Cement Company at Nazareth, showing over-head tram for conveying cement rock to the mill.

Plate XII B. View in the quarry of the Bath Portland Cement Company. The face of the quarry at highest point is about 90 feet.

Plate XIII A. Another view of the Bath Portland Cement Company's quarry showing face of quarry, from 60 to 90 feet high and showing churn drills at work, drilling holes 6 inches in diameter the full depth of the quarry face.

Plate XIII B. View north of the Atlas Cement Co's quarry looking northeast, showing the slaty character of the rather highly argillaceous limestone (cement rock). The slaty cleavage dips to the south. The gentle undulations visible in the cleavage are produced by the cleavage passing at an angle across the beds, which here dip at an angle of 40° to the north.

Plate XIV A. View in the quarry of the Lehigh Portland Cement Company at Fogelsville.

Plate XIV B. Quarry in Nazareth limestone at West Coplay. This quarry furnishes limestone for the American and Lehigh Portland Cement Companies.

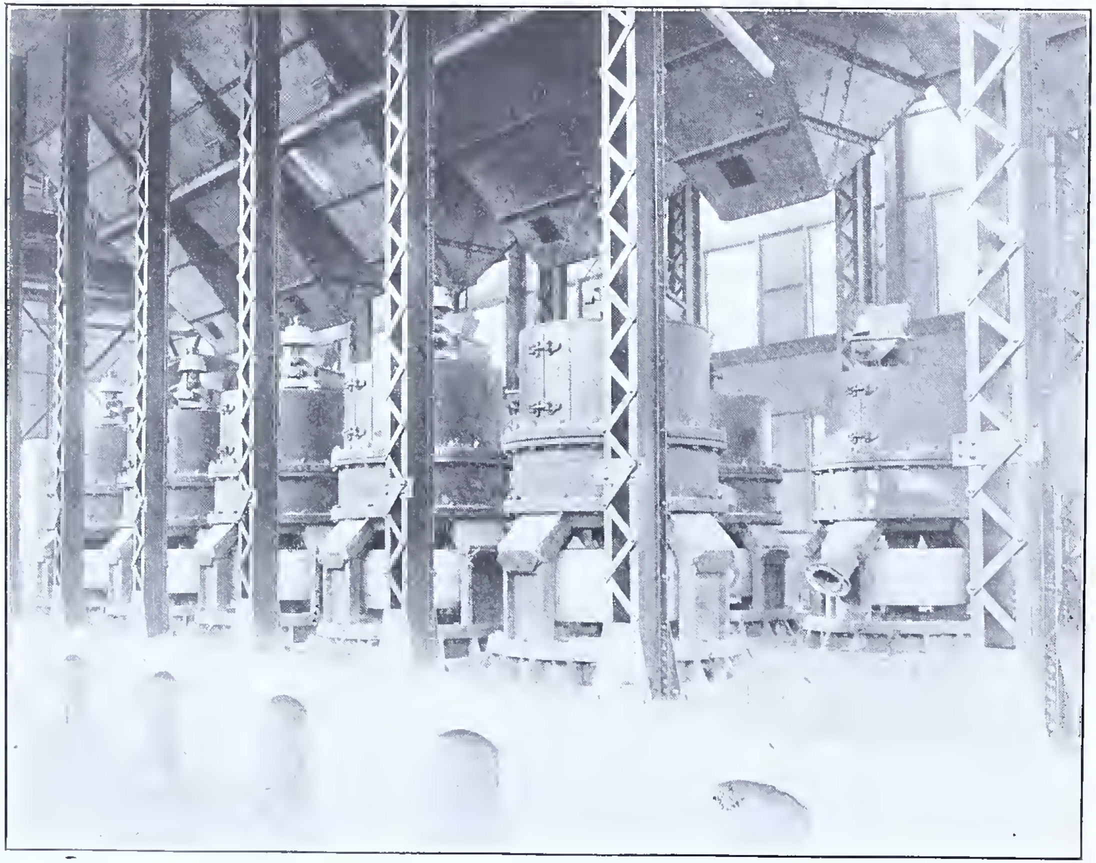

Plate XV A. Battery of 42-inch Lehigh Fuller mills in the plant of the Allentown Portland Cement Company at Evansville, Pa.

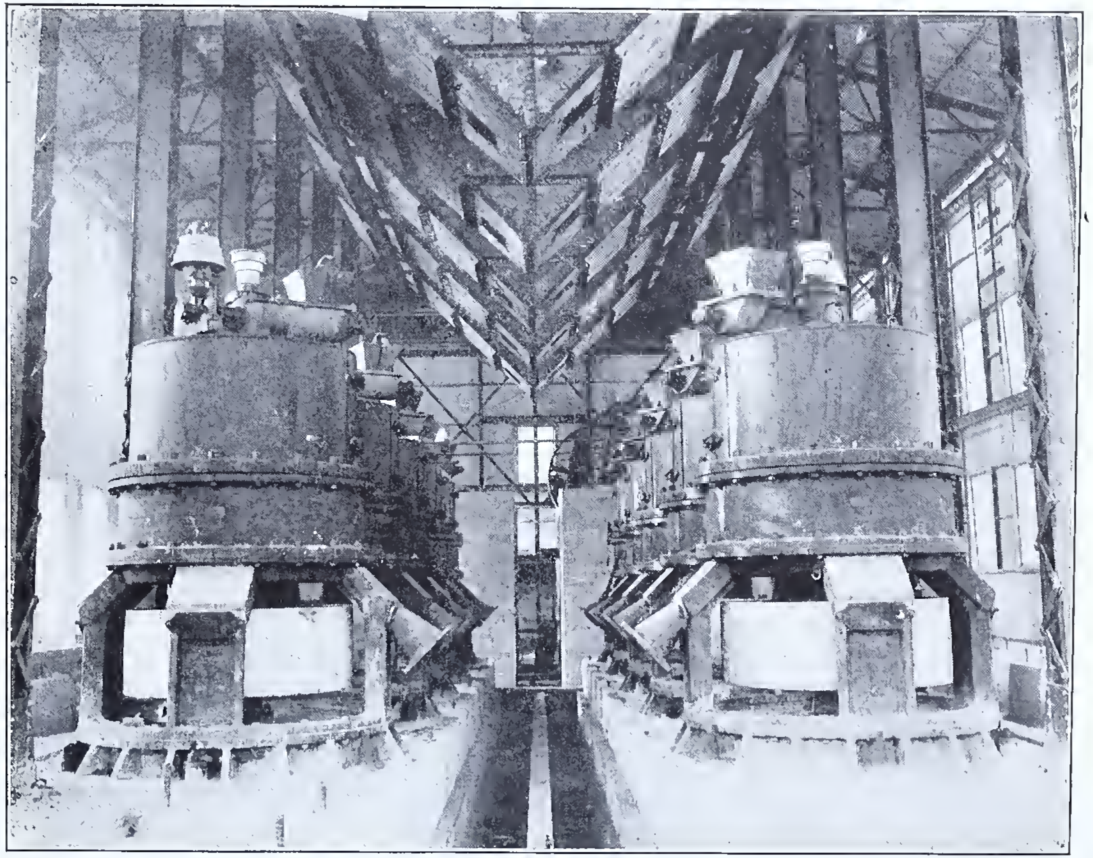

Plate XV B. Battery of 42-inch Lehigh Fuller mills in the plant of the Allentown Portland Cement Company at Evansville, Pa.

ready for roasting has such a fineness that from 82 to 90 per cent. of it will pass a 100-mesh sieve. A recent development in the form of pulverizing machinery, is the Fuller-Lehigh mill, which has been installed in a number of plants throughout the Lehigh Districst, as well as in others scattered throughout the United States. The mill is manufactured by the Fuller Engineering Company, home office at Catasauqua, Pa., who claim for their new 42 inch mill far greater economy in the use of power and in cost of maintenance than can be obtained from any other pulverizer on the market.

The growth of the cement industry in the United States within the past ten years has been due largely to the introduction of the rotary kiln, which was invented by Ransom in England, about twenty-five years ago, but was never successfully operated by its inventor. It was left to the skill and persistency of American mechanical engineers to add the last and greatest impulse to the industry. In 1888 the Atlas Portland Cement Company at Northampton, Pa., installed the first rotary kiln, and after much experimenting, succeeded in operating it successfully. This kiln is a steel cylinder, six or seven feet in diameter at one end and tapering somewhat toward the other. As used up to a few years ago, the kilns were about six feet in diameter and sixty feet long. They were mounted then as now in a slightly inclined position, the inclination being about three-fourths of an inch to a foot. The kiln is lined with fire brick (or occasionally with brick made of cement clinker) to withstand both the high temperature and to resist the corrosive effect of the fused rock. This great tube is mounted in two or more riding rings, each ring on two or four idlers, and made to rotate slowly at the rate of about one revolution in ten minutes. The ground mixture is fed in at the upper end by a screw conveyor, protected by a water jacket. As the kiln slowly revolves the ground rock works its way down into the "fire zone" toward the lower end of the kiln, and is there reduced to a semifused condition and in this condition passes out at the lower or discharging (larger) end in the form of white hot clinker. This lower end of the kiln projects into a movable hood which acts as a shield to protect a nozzle-like burner through which finely pulverized bituminous coal is forced by air blasts. This finely pulverized coal ignites with a series of explosions, producing a temperature in the firing zone of about 2,500° F.

In the 60 foot kiln not more than 25 per cent. of the heat developed is actually utilized in the burning of the clinker, the remaining 75 per cent. being lost. In modern practice experiments are being made with two methods for saving some of this wasted heat.

1. The lengthening of the kiln, thus giving the material a longer time in which to absorb the heat, and at the same time greatly increasing its capacity.

4

2. Passing the gases of the kiln through upright boilers and then through an economizer. This latter experiment has yielded little of practical value, while the first has proven a success, and has accomplished the saving in heat which its originator, Mr. Thomas A. Edison, predicted it would. As a result, the plants of the region are installing kilns 120 to 140 feet in length. The Edison Portland Cement Co. at Stewartsvilie, N. J., began by installing four 150 foot kilns. The Alpha Portland Cement Co. have installed ten 140 foot kilns in their new plant at Martins Creek. The Dexter Portland Cement Co., at Nazareth is installing 120 foot kilns, while other plants throughout the region are installing kilns varying in length from 110 to 140 feet. It has now been demonstrated by actual experience that the average capacity in barrels per day is as follows; for a

60-foot kiln, 200 barrels.
100-foot kiln, 400 barrels.
120-foot kiln, 500 barrels.
150-foot kiln, 750 barrels.

The writer is informed on good authority that the amount of fuel in the form of pulverized coal required to properly calcine enough clinker to make a barrel of cement in a

60-foot kiln is 110 pounds.
80-foot kiln is 100 pounds.
110-foot kiln is 90 pounds.
150-foot kiln is 80 pounds.

While the above estimates are approximate, and may vary somewhat in different mills and under varying conditions, it is obvious that up to a certain limit at least, the lenghtening of the kiln results in an economy of fuel. To what limit this lengthening process could be profitably carried in actual practice is apparently undetermined. The general opinion which seems to prevail among practical cement makers is that in the 140 or 150 foot kiln this limit has been reached. The cooled clinker is a hard, semi-vitrified, lumpy to finely granular, dark greenish-gray substance when properly burned. When insufficiently burned it is brownish in color.

The grinding of the clinker constitutes what is known as the finishing process and is accomplished in the same way as the grindng of the raw materials. The first step in the reduction of the clinker is accomplished in the ball mills. From them it is fed to tube mills. On emerging from these it should be so fine that 90 per cent. will pass a 100 mesh sieve. In color it should be cold bluish-gray, not brown, and should have a specific gravity, when freshly ground, of 3.0 or 3.1. After grinding, the finished product is conveyed to the stock house where it remains in bins for a few weeks or months to "ripen." This

Plate XVI. Atlantic Portland Cement Company's mill at Stockertown in process of erection, showing a battery of twelve 120 foot kilns in position.

Plate XVII. View of Mill H of the Lehigh Portland Cement Company at Fogelsville.

ripening process consists of certain chemical changes, the most important of which is the hydration or slacking of the relatively small percentage of free lime almost invariably present. It may also absorb a certain amount of carbonic acid, the amount of the absorption of this gas depending upon the opportunity it has for so doing. This results in a slight lowering of the specific gravity. During a period of six months Portland cement may lose from 4 to 7 per cent. of its original weight and then may have a specific gravity of 2.9, but it ought not to fall below this. Should it do so the fact is usually interpreted as meaning too much uncombined or free lime, which may mean either an over-limed or under-burned cement. Other things being equal, the more thorough the burning the higher the specific gravity, the maximum being 3.15 in well-balanced mixtures.

During the entire process of manufacture a most careful watch is kept upon the chemical composition of both the raw and the finished materials. Frequent chemical analyses of average samples from the quarry are necessary to determine how much limestone or clay must be added. The mud from drill holes is used as an index of the average of the quarry.

Natural or Rosendale Cement. Besides Portland cement a considerable amount of Natural or Rosendale cement was formerly manufactured in the Lehigh region, but owing to improved methods in the manufacture of true Portland cement, it has been nearly or quite displaced by the latter. This variety is made by burning the rock just as it comes from the quarry in vertical kilns at a temperature only great enough to drive off the carbonic acid, in the same way that limestone is burned in making lime, and then pulverizing the burned product. The resulting "Natural Cement" is quick setting but slow in hardening and never attains the strength of true Portland. For underground or underwater construction, where a rapidly setting cement is required and where great strength is not necessary, it may serve the purpose quite as well or possibly better than Portland. The amount at present manufactured, however, is small.

The rock used in the manufacture of natural cement is low in lime, having usually not more than 60 to 70 per cent. $CaCO_3$, and is taken from those beds in the Lehigh limestone series which lie well up toward the overlying slates.

By mixing three parts of natural cement with one of Portland an intermediate variety was at one time produced called "Improved Natural Cement," which is materially stronger than the natural. This grade is made by grinding together three parts of the burned natural cement rock and one part of clinker from the rotary kilns.

Puzzolan Cement. Puzzolan cement, manufactured by mixing blast-furnace slag, with slaked lime, has been manufactured since

1896 at various places in the United States, but its production is on the decline, and inasmuch as none is manufactured in the Lehigh District, no farther mention need be made of it.

Slag Cement. Slag cement is manufactured from a mixture of blast-furnace slag and limestone. It is in every sense a true Portland cement, and might be described as a bi-product of the Steel industry of the Country. At present it is being produced by the United States Steel Corporation at their plant at Pittsburgh, Pa., in quantities large enough to materially increase the total output of the Country. The subsidiary Company of the Steel Corporation which manufactures the cement is known as the Universal Portland Cement Company.

TESTING THE PROPERTIES OF CEMENT.

It is not alone sufficient that cement should come up to the standard as regards chemical composition, for it might satisfy all of the conditions of a rigid chemical examination and still be faulty as a construction material. This might result from an improper blending of the raw materials or from insufficient burning, or again, from imperfect grinding of the clinker.

In order to be accounted thoroughly safe and capable of performing its responsible mission, it should be made to stand the following tests: (1) Setting properties, (2) soundness, (3) strength, (4) specific gravity, (5) fineness.

1. *Setting Properties.*—These, while not of the very first importance, are essential. There may be and in fact nearly always is considerable variation in the time of set between different brands of cement or, for that matter, between different samples of the same brand, one of the difficulties in the manufacture being to bring this variation within the usual specification limits.

Initial and Final Set.—The setting time of cement is commonly determined by means of the so-called Gilmore Needles (a method proposed by General Gilmore, U. S. A.). The apparatus consists of two vertically placed needles or wires, properly supported so that they can be raised and lowered. The larger of the wires is one-twelfth inch in diameter and is weighted with a one-fourth pound weight. The small is one-twenty-fourth inch in diameter and is weighted with a one pound weight.

A portion of cement is moistened with just enough water (which should have a temperature of from 60° to 70° F. and which in quantity would be about 20 per cent. by weight of the sample taken) to make it cohere and is then made into a thin cake upon a piece of window glass usually four or five inches square. The cake or "pat," as it called, is about three inches in diameter and one-fourth inch thick at the centre and thins away at the edges. When the pat will support

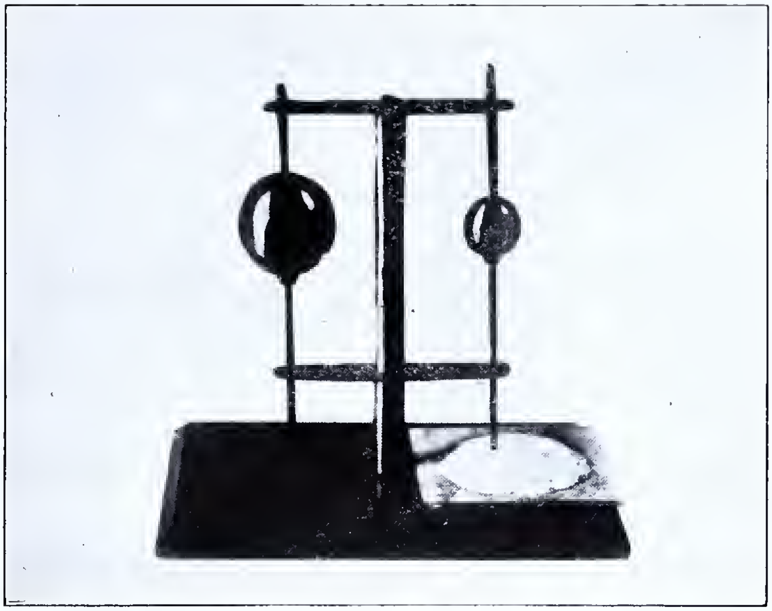

Fig. 3. Gilmore needles.

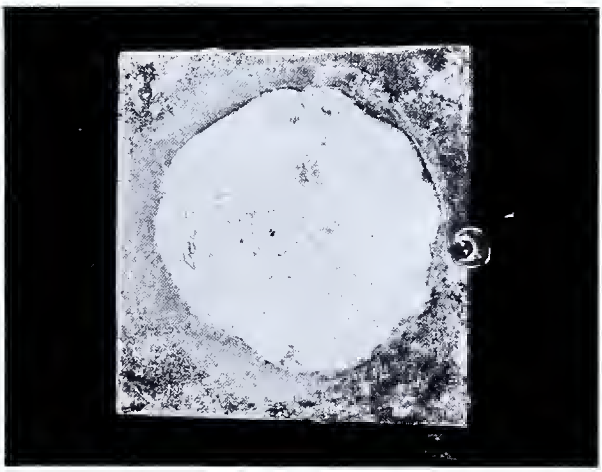

Fig. 4. Sound pat. Shows no cracking or curving.

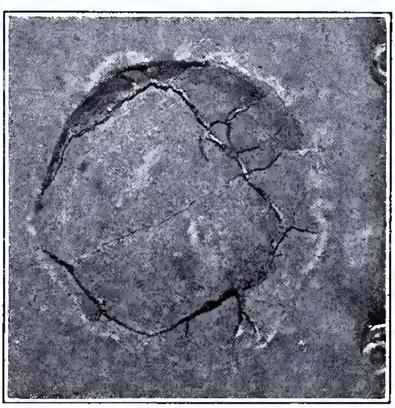

Fig. 5. Unsound pat. Shows cracking or "blowing."

the one-twelfth inch wire weighted with the one-fourth pound weight it is said to have acquired its "initial set," and likewise when it will support the smaller needle with the greater weight it has acquired its "final set."

According to standard specifications, Portland cement must develop initial set in not less than thirty minutes but must develop final set in not less than one hour, nor more than ten hours.

For natural cement the intial set should develop in not less than ten minutes and final set in not less than thirty minutes nor more than three hours.

2. *Soundness.*—This is the most important property of Portland or natural cement, but unfortunately is perhaps the most difficult to determine with absolute certanity.

Portland cement is considered sound or constant in volume after successfully undergoing the following tests:

Three pats are made of which one is kept in air at normal temperature and observed at intervals for at least twenty-eight days; the second is kept in water at as near 70° F. as practicable and observed at intervals for the same period of time. The third is exposed in an atmosphere of steam above boiling water in a loosely closed vessel for five hours. If these pats at the end of these periods of time remain hard and firmly attached to the glass (i. e., do not curve and leave the glass) and show no signs of distortion, craking, checking or disintegrating, the cement is pronounced sound.

3. *Strength.*—The object here is to determine as accurately as possible the strength which a given cement will develop within a certain period of time and by comparing its increase of strength as shown at the different dates of testing, to arrive at some conclusion as to its ultimate strength. For this purpose a weighed sample is mixed with just enough water (usually about 20 per cent.) to render it plastic and then packed into moulds, which in ground section are sheaf-shaped and which at the center have a cross-section of one square inch. These moulded samples are called "briquettes" and a single form or mould usually holds five briquettes. A great deal depends upon the skill of the operator in the making of briquettes and in the hands of different operators a wide variation in results may be expected. In other words, the personal equation enters so largely into the problem that cement testing in this particular phase, is in a very unsettled state, at least in so far as scientifically accurate and uniform results are concerned.

The briquettes are prepared in two ways, viz.; by mixing pure cement (neat briquettes); or by mixing one part cement with three parts of standard sand, which is a uniform article especially prepared for the purpose (sand briquettes).

The briquettes thus made are allowed to set one day (twenty-four hours) in moist air and after that are immersed in water. At periods of one, seven and twenty-eight days they are broken by tension in machines especially constructed for that purpose (of which the most common in use are the Fairbanks, the Olsen and the Riehle) and the tensile strength in pounds per square inch determined. The minimum strength required in order to satisfy the usual standard specifications, which strength must never show serious retrogression, may be expressed as follows:

NEAT CEMENT.

Age.	Strength per Sq. in.
1 day (in moist air), ...	150-200 pounds.
7 days, ...	450-550 pounds.
28 days, ...	550-650 pounds.

1 Part Cement, 3 Parts Sand.

Age.	Strength per Sq. in.
1 day, ...	150-200 pounds.
28 days, ...	200-300 pounds.

The following table gives an idea of the relative strength of Portland, improved natural and natural cement.

	1 Day.	7 Days.	28 Days.	3 Mos.	6 Mos.	1 Year.	2 Years.
Portland (neat), pounds,	300	730	840	875	895	900	920
Improved (neat), pounds,	100	230	360	450	550	520	540
Natural (neat), pounds,	85	130	190	305	350	380	415
Portland (1 : 2),	--------	300	400	450	480	505	500
Improved (1 : 1),	--------	220	360	540	670	680	715
Natural (1 : 1),	--------	65	115	210	265	275	290

As will be observed in the second table, improved cement shows a greater actual strength when mixed with sand than when mixed neat.

According to standard specifications natural cement must show a minimum strength, with no retrogression of the same, as follows:

NEAT.

Age.	Strength per Sq. in.
1 day, ...	50-100 pounds.
7 days, ...	100-200 pounds.
28 days, ...	200-300 pounds.

Fig. 6. Brass moulds used in making briquettes.

Fig. 7. Briquette before and after breaking.

1 Part Cement, 3 Parts Sand.

Age.	Strength per Sq. in.
1 day,	25-75 pounds.
28 days,	75-150 pounds.

The chemical composition of Portland cement is obviously of the utmost importance. A careful and extended study of the tensile strength of cement when compared with its chemical composition has resulted in a high degree of accuracy and efficiency in the manufacture of the article. It has been previously stated that the chemical composition of the raw mixture is of vital importance and that the amount of carbonate of lime in the mixture should be between 73 and 74 per cent. of the total. Experience shows that a raw mixture carrying 73.8 per cent. of lime carbonate will make a cement carrying approximately 62.5 per cent. of lime (CaO) and that the best (strongest) cements have about this proportion of lime. But the lime is of no more importance than the other ingredients, viz.; the silica (SiO_2), Alumina (Al_2O_3) and the iron (Fe_2O_3) which are the constitutents of the clayey ingredient of the raw mixture. The relation of these various molecules or constituents, i. e. the Silica, the oxide of iron, the oxide of alumina, and the oxide of lime, can best be expressed in ratios, and of these there are two which must be watched most carefully. The first, is the ratio of the Silica to the Alumina, determined by dividing the percentage of the Silica (SiO_2) in the cement, by the percentage of Alumina (Al_2O_3) which it contains. This is known as "The index of activity" for the reason that this ratio largely determines the quick or slow setting nature of the cement, and also in part its ultimate strength. The second is the ratio of the lime, to the Silica, Alumina and iron, and is determined by dividing the percentage of lime (CaO) in the cement, by the sum of the percentages of the Silica (SiO_2), Alumina (Al_2O_3) and iron (Fe_2O_3). This ratio is known as the "Lime ratio." The effect of the two ratios, i. e. the bearing of the relative amounts of these different constituents, on the strength or cementitious value of the cement, is best illustrated by the following table, which compares the chemical composition of twelve different samples of Portland cement with their tensile strength. For this table the author is indebted to Mr. Richard K. Meade, General Manager of the Tidewater Portland Company, who has an international reputation as a cement chemist.

TABLE SHOWING THE EFFECT OF CHEMICAL COMPOSITION ON TENSILE STRENGTH.

Cement Specimens.	Analysis.					Ratios.		Tensile Strength in Pounds per Square Inch.											
	Silicia, SiO_2.	Iron Oxide, Fe_2O_3.	Alumina, Al_2O_3.	Lime, CaO.	Magnesia, MgO.	"Index of Activity." $\frac{\%SiO_2}{\%Al_2O_3}$	"Lime Ratio." $\frac{\% CaO}{\%SiO_2+\%Al_2O_3+\%Fe_2O_3}$	1 Day Neat.	7 Days Neat.	28 Days Neat.	3 Months Neat.	6 Months Neat.	1 Year Neat.	7 Days 1-3 Sand.	28 Days 1-3 Sand.	3 Months 1-3 Sand.	6 Months 1-3 Sand.	1 Year 1-3 Sand.
A,	20.80	2.48	8.00	62.30	3.00	2.60	1.99	320	840	950	895	910	990	340	410	425	450	445
B,	21.02	2.40	7.54	61.53	3.45	2.79	1.99	210	828	921	910	905	945	325	415	410	460	475
C,	21.78	2.55	7.02	62.70	2.88	3.10	2.00	220	775	888	925	910	925	275	410	400	440	453
D,	22.20	2.98	6.26	62.85	2.10	3.55	2.00	245	635	740	755	785	835	225	335	388	410	440
E,	23.98	2.60	5.12	63.15	1.88	4.68	1.99	235	585	695	713	758	805	185	275	310	360	393
F,	24.42	3.10	4.22	62.86	1.57	5.79	1.98	210	510	645	666	710	755	165	245	283	298	335
G,	19.91	2.25	7.37	63.88	3.04	2.70	2.16	212	1,048	968	945	955	960	330	395	375	380	395
H,	20.42	2.30	7.52	63.26	3.12	2.72	2.09	260	885	1,004	995	1,028	1,036	345	435	458	485	510
I,	20.48	2.23	7.65	62.75	2.98	2.71	2.04	315	760	865	860	915	985	303	410	403	445	467
J,	21.20	2.35	7.85	62.13	3.06	2.70	1.98	310	710	825	815	888	903	260	338	360	388	403
K,	21.51	2.23	7.97	61.70	3.03	2.70	1.94	346	610	725	750	789	828	228	298	316	336	387
L,	21.94	2.38	8.10	60.95	3.16	2.71	1.88	410	525	610	625	675	693	193	260	285	310	345

A comparison of cements A, B, C, D, E and F will show the relation between the relative percentages of silica and alumina to the tensile strength. While a comparison of cements G, H, I, J, K and L will show the relation between the relative percentage of lime on the one hand and of silica iron oxide and alumina on the other to the tensile strength. It will be seen that the best results are obtained, when the "index of activity" is 2.7 to 3, that is, when the cement carries from 20 to 21 per cent. of silica and 7.3 to 7.6 per cent. alumina; from 62 to 63 per cent of lime; and when the "lime ratio" stands obout 2.00; that is when the cement contains about 20 per cent silica, 7.3 to 7.6 per cent alumina, and 62.5 to 63.5 per cent lime. When either one or both of these ratios exceed or fall below these amounts, as for example in D, E and K, L, the loss in strength is considerable.

4. *Specific Gravity.*—The specific gravity of Portland cement has already been referred to and as stated should not fall below 3.1. For natural cement 2.8 is the minimum.

5. *Fineness.*—Standard specifications require that Portland cement must be ground to a fineness such that it will leave by weight a residue of not more than 8 per cent. on a 100-mesh sieve.

The same regulations require that natural cement shall leave a residue of not more than 10 per cent. on a 100-mesh sieve and not more than 30 per cent. on a 200-mesh sieve.

PRODUCTION OF PORTLAND CEMENT IN THE LEHIGH DISTRICT COMPARED WITH THE TOTAL PRODUCTION OF PORTLAND AND OTHER CEMENTS IN THE UNITED STATES.

The Lehigh District which was the cradle of the Portland Cement industry in the United States, was for many years the chief, in fact the only producer of the article, and it is here that most of the problems connected with its manufacture, such as the perfecting of the process and devising ways for greater economy in production, have been solved. The following facts with regard to the production of cement in the United States have been taken from "Mineral Resources of the United States" for the year 1908, as given in the excellent article by Edwin C. Eckel of the U. S. Geological Survey, in which he gives a summary of the conditions of the industry for that year.

The birth of the Portland Cement industry in the United States, as above stated, dates from the year 1879. From 1880 to 1883, less than 100,000 barrels of cement were manufactured yearly, beginning with

42,000 barrels in 1880. From 1884 to 1890 the production increased from 100,000 to 335,500 barrels. Between 1890 and 1895 the production steadily increased to 990,324 or nearly a million barrels. Since then the increase has been somewhat phenomenal, culminating in 1908 with 51,072,912 barrels.

During most of the time from the inception of the industry to the present, the Lehigh District has been the chief producer. But for the past ten years the development of the industry in other states, notably New York, Ohio, Michigan, Indiana, Illinois, Kansas and Missouri, to say nothing of other States farther West, has so distributed the production that the Lehigh District to-day produces less than one-half of the total output of the United States. Previous to the year 1908 the Lehigh District produced annually from 50 to 75 per cent. of all the Portland Cement made in this Country except for the years 1905 and 1906, when it produced 49 per cent. And for the first time in 1908 it took a backward step, failing by 4,217,299 barrels of reaching the previous year's record. The accompanying table compares the total annual production of Portland Cement in the United States with that of the Lehigh District, during the interval 1890-1908. It also shows the decline in the production of Natural Cement and the steady and rather remarkable growth in the production of slag cement, which last item accounts for all of the increase in production of the United States for the year 1908. Slag Cement is apparently a factor to be reckoned with in the future.

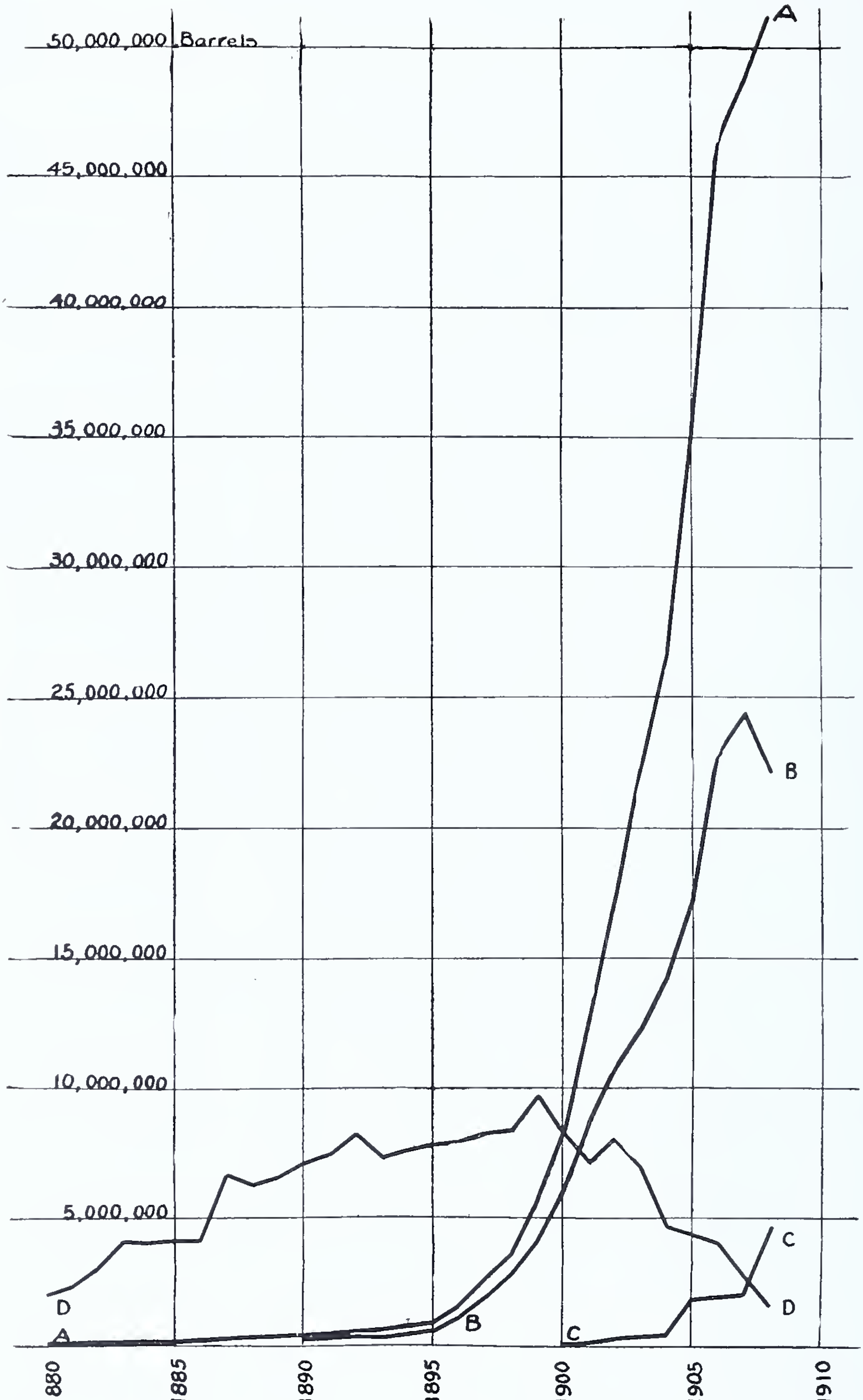

Figure 8. Diagram showing the total production of Portland Cement in the United States in barrels, (line A.), as compared with that of the Lehigh District, (line B.), also amount of Slag Cement, (line C.) and Natural Cement, (line D.). Line A includes amounts represented by lines B and C.

This table was compiled from the report of Mr. Eckel above referred to.

TABLE SHOWING TOTAL AMOUNT, IN BARRELS, OF PORTLAND, NATURAL (ROSENDALE) AND SLAG CEMENTS MADE IN THE UNITED STATES FROM 1890 TO 1908; ALSO COMPARATIVE AMOUNT OF PORTLAND CEMENT MANUFACTURED IN THE LEHIGH DISTRICT DURING THAT PERIOD.

	Portland cement. Total production.	Portland cement. Production in Lehigh district.	Per cent. Lehigh district.	Natural cement.	Slag cement.
1890,	335,500	201,000	60.0	7,082,204	
1891,	454,813	248,500	54.7	7,451,535	
1892,	547,440	280,840	51.3	8,211,181	
1893,	590,652	265,317	44.9	7,411,815	
1894,	798,757	485,329	60.8	7,563,488	
1895,	990,324	634,276	64.0	7,741,077	
1896,	1,543,023	1,048,154	68.1	7,970,450	
1897,	2,677,775	2,002,059	74.8	8,311,688	
1898,	3,692,284	2,674,304	72.4	8,418,924	
1899,	5,652,266	4,110,132	72.7	9,868,179	
1900,	8,482,020	6,153,629	72.6	8,383,519	32,443
1901,	12,711,225	8,595,340	67.7	7,084,823	164,316
1902,	17,230,644	10,829,922	62.8	8,044,305	318,710
1903,	22,342,973	12,324,922	55.2	7,030,271	462,930
1904,	26,505,881	14,211,039	53.7	4,866,331	473,294
1905,	35,246,812	17,368,687	49.3	4,473,049	1,735,343
1906,	46,463,424	22,784,613	49.0	4,055,797	2,076,000
1907,	48,785,390	24,417,686	50.0	2,887,700	2,129,000
1908,	51,072,612	20,200,387	39.6	1,686,682	4,535,300

The accompanying diagram is intended to show graphically four things, viz.; 1st: the phenomenal growth of the Portland Cement industry in the United States, starting with a production of 42,000 barrels in 1880 and culminating with 51,072,612 barrels in 1908. The rapid increase in the number of cement plants in the Lehigh District, is chiefly responsible for the impetus acquired by the industry during the period 1895-1905. Since 1905 but four new cement plants have been built within the Lehigh District, and the increase in total production has been due to the development of the industry in other States of the Union and to the rapid increase in production of slag cement, of which the Universal Portland Cement Company at Pittsburg, a subsidiary company of the United States Steel Corporation, is at present the only producer. 2nd: The decreasing importance of the Lehigh District, due largely to the rapid development of the industry elsewhere throughout the United States. So far as abundance and character of materials are concerned, to say nothing of geographic position, the Lehigh District will probably always have an advantage

over any other section of the country. 3rd: The decline in the manufacture of Natural (Rosendale) cement owing to a perfecting of the process in the manufacture of Portland cement, for which the introduction and increase in length of the rotary kiln is largely responsible, thus making it possible to manufacture Portland cement as cheap or more cheaply than natural cement. 4th: The appearance and rapid growth in the production of slag cement. This grade of cement is in all respects true Portland cement and is undoubtedly a factor to be seriously considered in the future development of the industry. Beginning with 32,443 barrels in 1900, its production rapidly increased to 4,535,300 in 1908. It was the increase in this particular kind of cement which sustained the strongly aspiring line representing the total production of the United States for the years 1907 and 1908. For the sake of comparison, however, a separate line was plotted, showing the rapid growth in production of this new kind of cement.

PRICE OF CEMENT.

The improvement in the process of manufacture, resulting in a great reduction in the actual cost of manufacture, together with the enormous increase in production, has resulted in the inevitable and steady fall in the market price of the article. The attending diagram, which was also taken from Mr. Eckel's article in "Mineral Resources of the United States," 1908, shows a rapid general decline, with several alternating bullish and bearish tendencies, beginning with a maximum of $3.00 per barrel in 1880 and reaching low water mark of $.85 per barrel in 1908.

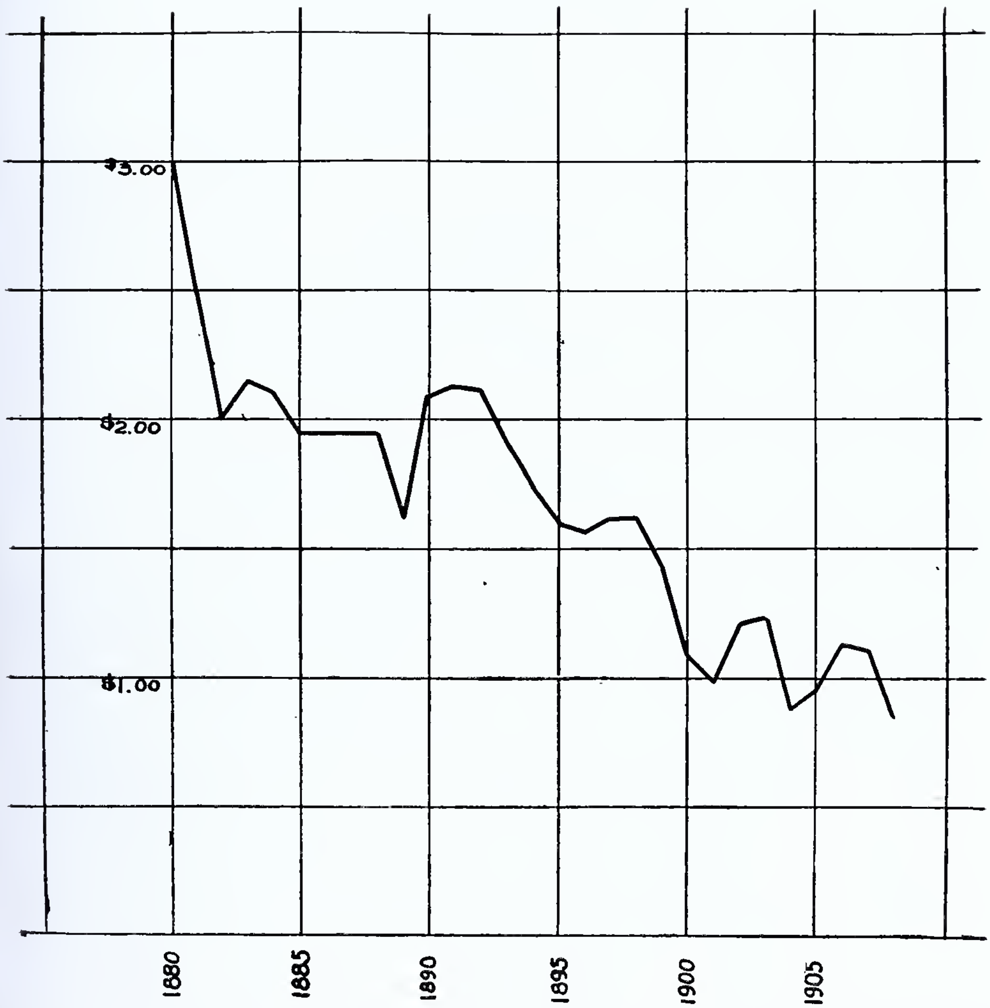

Figure 9. Diagram showing decrease in average price per barrel of Portland Cement from 1880 to 1908.

DIRECTORY OF COMPANIES MANUFACTURING PORTLAND CEMENT.a

Operator.	Office.	Works.
Allentown Portland Cement Company, J. W. Fuller, Jr., Managing Director.	693 Allentown Bank Building, Allentown, Pa.	Evansville, Pa.
Alpha Portland Cement Company, A. F. Gerstell, General Manager.	First National Bank Building, Easton, Pa.	Martins Creek, Pa. Alpha, N. J. Manheim, W. Va.
American Cement Company, J. W. Eckert, Manager.	Egypt, Pa.,	Egypt, Pa.
Atlantic Portland Cement Company,	356 Mills Building, San Francisco, Cal.	Stockertown, Pa.
Atlas Portland Cement Company, H. J. Seaman, General Supt.	Northampton, Pa., or 30 Broad St., N. Y.	Coplay, Pa. Northampton, Pa. Hannibal, Mo.
Bath Portland Cement Company, F. R. Frank, Superintendent.	Bath, Pa.,	Bath, Pa.
Blanc Stainless Cement Company, J. M. Carrere, Manager.	Allentown, Pa.,	Allentown, Pa.
Central Cement Company, John W. Eckert, Superintendent.	Egypt, Pa.,	Egypt, Pa.
Clinton Portland Cement Company, C. W. Friend, Manager.	Box 177, Pittsburg, Pa.,	Pittsburg, Pa.
Conestoga Portland Cement Company, J. W. Williams, President. (Plant in process of erection.)	409 Woolworth Building, Lancaster, Pa.	Lancaster, Pa.
Coplay Cement Manufacturing Company, Charles W. Sarger, General Manager.	Philadelphia, Pa.,	Coplay, Pa.
Crescent Portland Cement Company, W. H. Hughes, Manager.	Wampum, Pa.,	Wampum, Pa.
Dexter Portland Cement Company, James Brobston, Manager.	Nazareth, Pa.,	Nazareth, Pa.
International Portland Cement Company, Joshua Hunt, General Manager.	Tenth and Sansom Streets, Philadelphia, Pa.	Elizabeth, N. J.
Lawrence Portland Cement Company, J. S. VanMiddleworth, Secretary.	1 Broadway, N. Y.,	Siegfried, Pa.
Lehigh Portland Cement Company, Joe Barr, Superintendent.	Young Building, Allentown, Pa.	Fogelsville, Pa. Omrod, Pa. West Coplay, Pa. Wellston, O. Mitchell, Ind.
Nazareth Cement Company, J. A. Horner, General Manager.	Nazareth, Pa.,	Nazareth, Pa.
New Castle Portland Cement Company, E. F. Norris, Manager.	New Castle, Pa.,	New Castle, Pa. (Hickory Township).
Northampton Portland Cement Company, H. A. Shaefer, Receiver.	Stockertown, Pa.,	Stockertown, Pa.
Penn-Allen Portland Cement Company, W. E. Erdell, General Manager.	Commonwealth Building, Allentown, Pa.	Penn-Allen (near Nazareth), Pa.
Pennsylvania Cement Company, H. L. Shock, Superintendent.	28 Cortlandt St., N. Y.,	Bath, Pa.
Phoenix Cement Company, G. F. Lindenmeyer, Superintendent.	Nazareth, Pa.,	Nazareth, Pa.
Reliance Cement Company, J. W. Eckert, Manager.	Egypt, Pa.,	Egypt, Pa.
Sandusky Portland Cement Company, S. B. Newberry, Manager.	Sandusky, O.,	York, Pa.
Shenango Portland Cement Company.	Young Building, Allentown, Pa.	New Castle, Pa.
Stewart Iron Company, Samuel McClure, General Manager.	Sharon, Pa.,	Sharon, Pa.
Universal Portland Cement Company, Edward Hagar, President.	Commonwealth National Bank Building, Chicago.	Pittsburg, Pa.
Vindex Portland Cement Company, Henry Ahrens, President. (Leased by Allentown Company.)	Baer Building, Reading, Pa.,	Molltown, Pa.
Whitehall Portland Cement Company, W. E. Erdell, Superintendent.	1722 Land Title Building, Philadelphia, Pa.	Cementon, Pa.

a This list includes not only those of the Lehigh District but of the entire State.

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TOPOGRAPHIC AND GEOLOGIC SURVEY of PENNSYLVANIA
GEORGE W. McNEES, ANDREW S. McCREATH, E. V. d'INVILLIERS, COMMISSIONERS
RICHARD R. HICE, STATE GEOLOGIST

GEOLOGIC MAP
OF PARTS OF
LEHIGH AND NORTHAMPTON COUNTIES PA.

Showing the distribution of the Materials used in the Manufacture of

PORTLAND CEMENT

ALSO THE OCCURRENCE OF

SERPENTINE AND TALC

By FREDERICK B. PECK

1.	Alpha Portland Cement Co., Mills, Nos. 1 and 2	Alpha, N. J.
2.	" " " " Mills Nos. 3 and 4,	Martin's Creek, Pa.
3.	American Portland Cement Co. Central Mill	Egypt, Pa.
4.	" " " " Reliance Mill	Egypt, Pa.
*5.	Atlantic Portland Cement Co.	Stockertown, Pa.
6.	Atlas Portland Cement Co, Mills 1, 2 and 3,	Northampton, Pa.
7.	" " " " Hercules Mill	Coplay, Pa.
8.	Bath Portland Cement Co.	Bath, Pa.
9.	Bonneville Portland Cement Co.	Siegfried, Pa.
10.	Coplay Cement Manufacturing Co.	Coplay, Pa.
11.	Dexter Portland Cement Co.	Nazareth, Pa.
12.	Edison Portland Cement Co.	Stewartsville, N. J.

*Plants in process of erection

13.	Lawrence Cement Co.	Siegfried, Pa.
14	Lehigh Portland Cement Co., Mill B	West Coplay, Pa.
15.	" " " " Mills A, D and F	Ormrod, Pa.
16.	" " " " Mill H	Fogelsville, Pa.
17.	Nazareth Cement Co.	Nazareth, Pa.
18.	Northampton Portland Cement Co.	Stockertown, Pa.
19	Penn Allen Portland Cement Co.	Bath, Pa.
20	Pennsylvania Cement Co	Bath, Pa.
21.	Phoenix Portland Cement Co.	Nazareth, Pa.
*22.	Quaker Portland Cement Co.	Sandt's Eddy, Pa.
23.	Vulcanite Portland Cement Co.	Vulcanite, N. J.
24	Whitehall Portland Cement Co.	Cementon, Pa.

*Plants in process of erection

SILURIAN

Shawangunk Grits — Ssh

ORDOVICIAN

Martinsburg Shale (HUDSON RIVER) — Om Crop

Lehigh Limestone (CEMENT ROCK) — Ol Crop

Nazareth Limestone — On

Coplay Limestone — Oc Crop

CAMBRIAN

Allentown Limestone — Ca Crop

Hardyston Quartzite — Ch

PRECAMBRIAN

Serpentine and Talc

Gneiss and Granite — Pg Crop

Plants ▪ Quarries × Normal Boundaries Faults Possible Faults

Approximate Boundaries

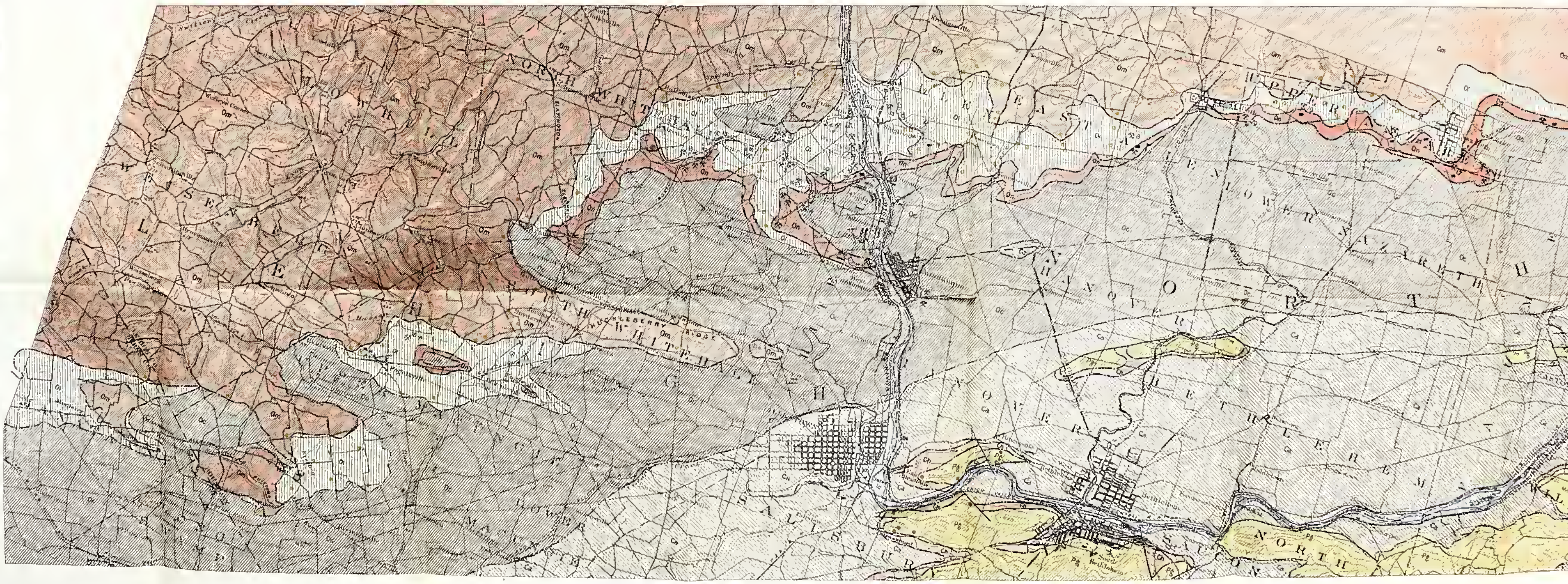
Scale

Miles

Kilometers

Contour interval 20 feet

Datum is mean sea level



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23.	Vulcanite Portland Cement Co.	Vulcanite, N. J.
24.	Whitehall Portland Cement Co.	Cementon, Pa.

*Plants in process of erection

Possible Faults ---------------